EXHIBIT 5

In re Flint Water Cases, No. 16-cv-1044

Expert Report of Dr. Larry L. Russell

June 30, 2020

Table of Contents

1 Scope of Engagement

This report provides my opinions relating to the City of Flint's April 2014 transition to distributing water from the Flint Water Treatment Plant that was sourced from the Flint River, the subsequent distribution of this highly corrosive water in the Flint drinking water distribution system, the substantial human health and property damage that resulted from the distribution of highly corrosive water (the "Flint Water Crisis"), and the role of professional engineering firms in the Flint Water Crisis. I have been asked by the Class Plaintiffs in the Flint Water Crisis litigation to evaluate the conduct of defendants Lockwood, Andrews & Newman, a division of defendant Leo A Daly (collectively, LAN), and Veolia North America (Veolia) as it relates to the Flint Water Crisis and the professional negligence claims against those defendants.

Specifically, I was asked to assess whether the professional engineering and consulting services provided by LAN and Veolia failed to satisfy applicable Standards of Care, the ethical standards applicable to the Engineering Profession, or otherwise were professionally unreasonable; and whether and how the conduct of the engineers contributed to the Flint Water Crisis and the resulting injuries to members of the proposed class.

It is my understanding that discovery is ongoing, and that the categories of damages that are available may change based on additional evidence that may become available. My opinions may change as a result of such additionally discovered information.

2 Summary of Conclusions

The Flint Water Crisis could have been prevented through the institution of reasonable engineering judgment, conventional water treatment technology and practice, and professionally competent understanding and application of knowledge of the interrelationships of the water constituents and their roles in causing corrosion.

My main conclusions, based on my experience as a professional engineer with expertise in water quality and water distribution systems, are, as follows:

- LAN and Veolia owed duties to both the City of Flint and its residents to perform their services in a manner that comported with professional standards, including ensuring that their work was protective of human health and property and did not create additional dangers to human health or property as is required by the engineering ethics codes of the National Association of Professional Engineers and the American Society of Civil Engineers.

- LAN and Veolia did not satisfy their duties as professional engineers because they:

  (a) failed to use, and insist upon the use of, standard assessments, including a root cause analysis, that any reasonably competent engineer would recommend using to identify the presence of highly corrosive water in the Flint water supply;

  (b) failed to propose a methodology for addressing corrosivity;

  (c) failed to convey the urgency of developing a Corrosion Control Treatment (CCT) plan for lead and copper based on an Optimal Corrosion Control Treatment (OCCT) evaluation for

Flint. The OCCT must be based on an optimization study that would have required implementing corrosion control to eliminate the risks of highly corrosive water. LAN and Veolia failed to perform a corrosion control study on the City's behalf and did not implement proper corrosion control;

(d) failed to identify the optimal corrosion control treatment as required in the EPA Lead and Copper Rule (Section 141.2) as "…the corrosion control treatment that minimizes the lead and copper concentrations at users' taps while insuring (sic) that the treatment does not cause the water system to violate any national primary drinking water regulations;"

(e) failed to identify the imminent risks to human health and property posed by the presence of highly corrosive water in the Flint water supply, and lead in the Flint plumbing systems;

(f) failed to recommend the correct form of CCT for the Flint River, which was at a minimum an orthophosphate-based treatment and pH control. These treatment requirements were identified in the Snell Environmental Group (SEG) 1998 report;

(g) failed to recommend that an immediate switch back to water supplied by the DWSD would have provided the most prompt and effective way to mitigate the damages caused by highly corrosive Flint River water, and achieve compliance with the EPA and MDEQ drinking water standards. As detailed below, there were numerous specific deficiencies in the work performed by both LAN and Veolia. Veolia compounded its errors and failed to act in accordance with the standard of care by subsequently refusing to accept their ethical obligation to protect the public health and the role its decisions played in the Flint Water Crisis.

- The absence of corrosion control treatment in the Flint water system following the April 2014 switch to water supplied from the Flint River resulted in substantial damage throughout the City, including: (1) the leaching of lead into the water, exposing residents to lead in their drinking water supply; and (2) damage to pipes and fixtures in residents' homes. The engineering deficiencies by LAN and Veolia contributed to high levels of total trihalomethanes (THMs), *legionella* outbreaks, and the general loss of a safe, reliable water supply during the Flint Water Crisis.

- All residences throughout the City of Flint were subjected to the damaging water supplied from the Flint River for approximately 19 months beginning in April of 2014.

- LAN could have prevented the Flint Water Crisis by identifying the potential for the production of corrosive water from the Flint River, and implementing an optimal corrosion control treatment study. That study was required to be performed prior to the switch over to the Flint River water, and would have exposed the need for corrosion control treatment. The failure of LAN to recommend an effective form of corrosion control resulted in enormous harm to human health and property.

- LAN chose not to recommend to the City that corrosion control should have been included in the list of upgrades to the Flint Water Treatment Plant in their memorandum to the City in August of 2013, as per Mr. Green. Corrosion control was in fact essential for the safe operation of this water treatment plant.

- LAN abdicated its responsibility, as the City's water quality advisor, and then claimed that its role was narrowed by the City, even though there is nothing to indicate that the scope of its obligations was in fact narrowed.

- LAN was the City of Flint's water treatment advisor by their contract with Flint. LAN's contract called out that changes in scope had to be made in writing. No such documentation exists altering or removing from their scope the role of water treatment advisor, as per LAN's Mr. Green.

- Although Veolia was not retained until February 2015, it also could have prevented much of the harm by acting quickly to identify and address the corrosive water in the Flint system. The failure to immediately address those issues allowed for continued harm to human health and property. Many of the problems of the Flint Water Crisis could have been mitigated by a recommendation for an immediate switch back to Detroit Water and Sewage Department (DWSD) water or at the minimum, the immediate implementation of corrosion control treatment.

- Veolia should also have worked with city and state officials to address the issues and restore public confidence. Instead Veolia downplayed the risks and did not address the critical issues that were impacting both property and human health throughout Flint.

3 Expert Qualifications

My name is Dr. Larry L. Russell, P.E. I have been retained by Class Plaintiffs in the Flint Water Crisis litigation. I am an expert in water quality assessments, corrosion mitigation, and the behavior of materials exposed to drinking water. I earned a BS, a MS, and a Ph.D. from the University of California at Berkeley in Civil/Environmental Engineering. I am registered Professional Engineer in the State of Michigan and in approximately 30 other states. I am registered as a Civil, Chemical, and Corrosion Engineer in the State of California. I am a licensed water treatment operator in California (T3), Hawaii, Texas, and Nevada, and a licensed distribution operator in California (D2). I am also a licensed contractor in California, holding the following classifications: A Engineering, B Building, C-10 Electrical, C-36 Plumbing, C-55 Water Conditioning, HAZ (hazardous substance removal), and ABS (asbestos).

I have in excess of 40 years of experience in water quality assessments, corrosion, and materials performance evaluations. I have been an elected director of the Marin Municipal Water District (MMWD) since 2004. MMWD is a water district that serves 190,000 people. Based on my 40 years of experience in the industry, I am familiar with the standards of care applicable to professional engineers in the water field. I have previously testified as an expert as to whether engineers have satisfied the applicable standard of care.

To prepare this report, I completed the following actions: I have reviewed the documents listed in the *Materials Reviewed* section. Reviewed documents include those prepared by Veolia, LAN, the Environmental Protection Agency (EPA), the Michigan Department of Environmental Quality (MDEQ), Professor Susan Masten, Professor Marc Edwards, and numerous depositions of witnesses involved in the water quality issues experienced during the Flint Water Crisis.

4 Opinions

4.1 Opinion 1

Opinion: The water quality crisis in Flint should have been directly addressed through the institution of proven conventional water treatment technology and practice. There were six root technical issues that caused the water crisis resulting from the use of the Flint River for drinking water between April 25th 2014 and October 16th 2015.

First: It is important to understand that metallic pipes are thermodynamically unstable in water, meaning they will corrode without protection. Therefore, corrosion control is a critical part of ensuring water quality and protection of household plumbing in a distribution system. Corrosion control is particularly important for a water distribution system that is considering a switch of water sources. The switch in water sources to the Flint River was likely to result in a high risk of distributing corrosive water. This risk results from high levels of chlorides, and a substantial increase in the Chloride Sulfate Mass Ratio (CSMR), which resulted in the distribution of highly corrosive water.

Sound engineering practice called for LAN to identify the fact that corrosion control optimization was essential *before* the switch to the Flint River. LAN should have developed and implemented an Optimized Corrosion Control Treatment (OCCT) strategy on the City's behalf, **before** switching water sources from Detroit to the Flint River water, as is required by the EPA Lead and Copper Rule.

After the switch was made to Flint River water, it was essential for LAN and Veolia to recognize that the absence of corrosion control created a ticking time bomb in the City's water supply and distribution system. LAN and Veolia should have conducted a root cause analysis to determine the cause of the water quality issues in Flint. Simply by conducting widely accepted and industry-standard calculations utilizing available data, like a CSMR, both LAN and Veolia would have ascertained that the Flint River water was highly corrosive, its use would result in enormous harm to both human health and property throughout the City due to the know presence of lead containing plumbing materials, and therefore the switch required a corrosion control evaluation **before** the switch over to aid in limiting these impacts.

Second: Neither LAN nor Veolia ever recommended that the City consider blending the treated Flint River water with the treated Lake Huron water from the Detroit Water and Sewage Department (DWSD). The City's Drinking Water could have been blended to immediately restore corrosion control to the City's water and would have reduced the overall corrosivity of the water. Blending would have achieved the City's goal of reducing the cost of the imported water, produced a more stable water, and maximized the use of the local water supply. The required facilities were in place to utilize blending, and blending could have been implemented at a lower cost than using solely imported DWSD water.

Third: Neither LAN nor Veolia ever recommended that the City simply switch back to the Lake Huron (DWSD) water that the City had used since 1967. The City's drinking water would have instantaneously been returned to the same quality it was prior to the switch by simply reconnecting to the DWSD system (although this would not have remediated all the damage to the residential plumbing already caused by the switch of the source water to the Flint River, it would have prevented further damage during the eight months after Veolia was retained that the City continued distributing corrosive Flint River water).

All facilities were in place that were required to make this switch back (as was eventually done in October 2015). The switch back could have been rapidly implemented, reducing the horrendous impact on the community that occurred while on the Flint River water.

Fourth: The City's consultants LAN and Veolia should have insisted upon the immediate installation of corrosion control (e.g., at a minimum orthophosphate injection and pH control, similar to the treatment for DWSD water). Implementation of corrosion control was critical to protect human health and property. Instead, neither consultant ever formally recommended that corrosion control treatment was necessary to protect human health and property.

Indeed, there is no written record of either consultant ever reviewing the water quality of the treated Flint River water with respect to corrosion or planning to conduct a corrosivity analysis of the treated Flint River water (as is required by the EPA Lead and Copper Rule [LCR]). Veolia appeared to view the corrosion issues in Flint as a nuisance that impacted the water aesthetics rather than as an urgent property and public health concern. Veolia treated their lack of recommendations for corrosion control as such.

The primary corrosion related recommendation made by Veolia was that a polyphosphate be utilized to cover up the red color in the water. The use of polyphosphate would have made the situation worse from a health and property preservation standpoint. Polyphosphates would have increased the rate of lead, copper, and iron corrosion during this period.

At a minimum, LAN and Veolia should have recommended the installation of the appropriate orthophosphate injection equipment and apply an appropriate dose of phosphate (low ppm levels).

Fifth: LAN and Veolia should have recommended to the City that it cease the usage of ferric chloride as a coagulant for removal of turbidity from the Flint River water.

The Flint River water contained high levels of chlorides resulting from both industrial and agricultural discharges, road salt used for winter ice management, and evaporation in Lake Holloway. The use of ferric chloride as a coagulant further increased the concentrations of chlorides in the treated water. Due in major part to the high chloride concentrations, and the resulting high CSMR values, the treated Flint river water was found to be up to ten times more corrosive to steel than the Lake Huron water provided by DWSD.

The use of ferric chloride further increased the high levels of chloride in the Flint River water, and also increased the CSMR, thereby making the water more corrosive. The consultants should have recommended switching back to Alum (Aluminum Sulfate), which was utilized in Flint in the 1950s and 1960s. The coagulant was changed to ferric chloride by recommendation of Alvord, Burdick and Howson (AB&H), and later adopted by both LAN and Veolia. Following their work, Veolia actually recommended increasing the ferric chloride dosage, which made the water even more corrosive.

The use of Alum would have provided suitable coagulation (especially in light of the fact that the Flint River plant provides Lime [and Soda] hardness removal, which also provides turbidity removal). Switching back to Alum would have decreased the chloride sulfate mass ratio (CSMR) and would have resulted in the reduction of the corrosivity of the water.

Sixth It is clear that neither AB&H, LAN, or Veolia understood the role that the interaction of the high TOC and ozone (originally recommended by AB&H) were playing on the corrosion of the iron and copper pipes. These factors together resulted in higher the levels of bacterial growth in the distributed water, and higher incidences of Microbial Induced Corrosion (MIC).

It has been well known, since at least 1983, that when waters with high TOC are ozonated with substantial doses of ozone (~5 ppm) that in addition to destroying some of the TOC, substantial portions of the TOC is converted from non-biodegradable carbon to biodegradable Assimilable Organic Carbon (AOC) or Biodegradable Dissolved Organic Carbon (BDOC).

Water is considered biologically stable when the AOC is less than 10 ppb and biologically unstable when the AOC is more than 50 ppb. The ozonated Flint River water was biologically unstable (Masten 2016). The production of AOC by ozonation directly resulted in several problems:

a) excessive biofilm growth in the City and homeowner's piping system due to AOC utilization

b) the excessive biofilm growth caused excessive chlorine demand in the City's distribution system

c) the excessive biofilm caused corrosion due to microbial induced corrosion (MIC) which contributed directly to the high levels of iron corrosion in the City's distribution system

d) the biofilm caused MIC in the copper pipes

d) the excessive levels of AOC lead to excessive biofilm production, which likely contributed directly to the *Legionella* outbreak that sickened nearly 100 and killed at least 12 people

Ammonia should have been added prior to ozonation to reduce the formation of Bromate (and the formation of chloramines following chlorination). The water treatment plant filters should have been operated to promote AOC reduction through biological activity, thereby reducing the potential for MIC. The engineers should have immediately recommended that pre-filter chlorination be ceased to enhance biological growth in the filters. This approach would have made it far more likely that the disinfectant levels would have been restored within the distribution system thereby minimizing MIC and additional biological growth.

4.2 Opinion 2

Opinion: Veolia practiced below the Standard of Care for engineers and water treatment operators.

The Veolia approach was piecemeal and did not demonstrate compliance with the following statement quoted from the Veolia webpage (veolianorthameria.com, accessed May 2020):

At Veolia, we're more than the world's leading provider of environmental solutions – we're dedicated to customized, cost-effective solutions that reflect the best practices, environmental protection and a better quality of life.

Veolia's egregious violations of the standard of care started with their failure to warn the City that the presence of highly corrosive water in the distribution system posed an immediate threat to human health and property. Veolia failed to insist that the absence of an optimized corrosion control plan be rectified. Veolia failed to conduct the most rudimentary corrosion evaluation calculations, such as the CSMR, which is a breach of the standard of care. Another of Veolia's serious mistakes was the failure to recommend that City immediately switch back to the corrosion control treated Lake Huron water (DWSD). Returning to DWSD would have eliminated the presence of highly corrosive water and prevented further damage to the residential plumbing already caused by the exposure to the highly corrosive Flint River water. Veolia violated the standard of care by failing to recommend to the City that the Flint water supply should have been treated with a corrosion inhibitor.

Veolia failed to recommend to the City blending of the treated Flint River water with the DWSD water. This approach would have immediately improved the City of Flint's water quality with respect to corrosivity.

4.3 Opinion 3

Opinion: LAN practiced below the Standard of Care for professional engineers and water treatment operators by failing to provide advice that was consistent with proven engineering water treatment practice.

LAN failed to identify the existence of highly corrosive water in the distribution system. LAN failed to alert the City of the need for corrosion control in their memorandum to the City on August 22, 2013, which was below the Standard of Care. As the City's water quality advisor, LAN crated a risk to human health and property by failing to conducting a corrosion control evaluation before making the switch to the Flint River. LAN breached the standard of care.

LAN failed to insist that their client install a corrosion inhibitor injection system prior to switching to Flint River water.

LAN failed to recommend that chloramination be installed to improve distribution disinfectant levels and reduce corrosion in the distribution system.

LAN failed to protect public health and property by insisting upon what Green referred to as a "shakedown cruise" pre-distribution test (Green 2020, Vol 1, p.117 L18-24) of the ability of the Flint River water treatment to continuously deliver quality drinking water that was non-corrosive and that would not cause harm to human health and property.

LAN abdicated its responsibility, as the City's water quality advisor, without any direction from the City (Green 2020, Vol 2 p.103 L18- p.107 L3).

4.4 Opinion 4

Opinion: LAN and Veolia's advice was below the Ethics standards for Professional Engineers and water treatment operators. LAN and Veolia failed to meet the first level of ethics rules of the National Society of Professional Engineers, namely, *Hold paramount the safety, health, and welfare of the public*

The LAN and Veolia personnel made many statements, which were simply untrue. In their internal communications, LAN and Veolia personnel acknowledged the problems and concerns that they saw and held, but they did not disclose these issues to their clients nor to the public (based on their presentation, report materials, and external emails) (Gnagy 2019, LAN reports from 2013-2015). The decisions and recommendations made by LAN (or more the lack thereof) directly contributed to the exposure of the citizens of Flint to high levels of lead, the outbreak of biological contaminants in the water system including *Legionella,* and the destruction of plumbing systems throughout the City of Flint.

4.5 Opinion 5

Opinion: LAN and Veolia failed to meet the standard of care when they did not provide advice to the City of Flint that would enable the City to meet all drinking water standards simultaneously.

4.6 Opinion 6

Opinion: The majority of houses in Flint were constructed before 1988 during the time when high lead solder was still in use. Nearly all houses were constructed before 2014 (over 99.99 percent) when high lead brass was in still in use. As a result, nearly all homes have lead containing plumbing components installed. These leaded plumbing components are subject to producing high lead levels in drinking water due to exposure to the Flint River water.

4.7 Opinion 7

Opinion: The switch to the highly corrosive Flint River water directly resulted in significant damage throughout the City's and property owners' plumbing systems. This corrosive water was uniformly distributed to all homes and businesses located throughout the Flint water system. Negative impacts to the plumbing systems included: the loss of pipe wall thickness, the potential initiation of copper pipe pitting corrosion, and increased galvanic corrosion. These negative impacts on the plumbing components are permanent and have reduced the life of the homeowners' plumbing systems, the value of their homes, and the useful life of the plumbing components. The only way to restore the losses resulting from exposure to the corrosive Flint River water is full house pipe and fixture replacement.

4.8 Opinion 8

Opinion: At this point, lead and lead containing materials (i.e., scales and particulates) are present in the plumbing systems throughout Flint. These lead containing plumbing materials include: lead service laterals, high leaded brass, high lead solder, lead pigtails (cast iron piping distribution system), galvanized pipe, and high lead content scale in PVC and copper piping.

This lead will be released episodically due to changes in water flow rate, plumbing repairs and replacements, and changes in drinking water chemistry. These releases cause ongoing lead exposure to the residents of Flint.

4.9 Opinion 9

Opinion: Every home and business in Flint received the highly corrosive Flint River water from April of 2014 through at least October 2015. The exposure to Flint River water impacted plumbing components by accelerating corrosion and increasing lead release into the drinking water. Every home and business suffered property damage to the premises plumbing and the residents were exposed to elevated levels of lead and iron in their drinking water. As a result of exposure to the Flint River water, all homes would have had endured one or more of the following issues:

(1) corroded galvanized pipe
(2) corroded high-lead brass fixtures
(3) pitted/corroded copper pipe
(4) corrosion at dissimilar metal connections [leaded solder-copper, brass-steel]
(5) particulate lead and/or lead containing pipe scale inside of the premise pipes, including those constructed of steel, copper, and plastic

4.10 Opinion 10

Opinion: LAN should have requested written direction from the City before abdicating its role as the City's water treatment advisor. LAN should have clearly communicated to the City that it was abdicating this role.

4.11 Opinion 11

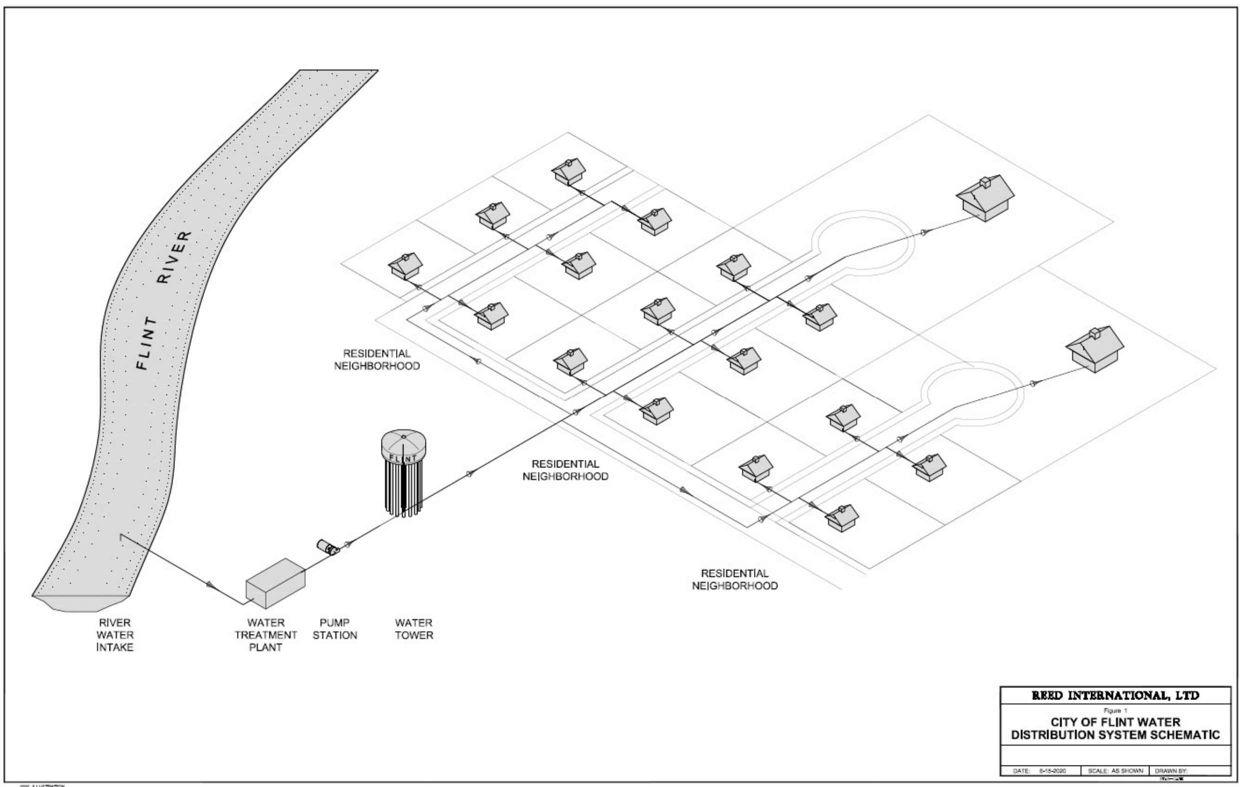
Opinion: As LAN's engineer subsequently acknowledged, it would be irresponsible to add chemicals to drinking water without careful and directed evaluations to demonstrate the efficacy of the chemicals. A corrosion control optimization study should have been conducted prior to the Flint River water plant startup. As the engineer, it as LAN's responsibility to recommend the completion of an Optimal Corrosion Control Treatment study before the switch, and its failure to do so did not comport with its professional obligations.

5 Historical Background

5.1 Water Distribution Systems

Typically, water distribution systems are built similar in structure to a tree. The water mains are the large diameter pipes that distribute water throughout the city and resemble the trunk and major branches on a tree. Each house is connected via a service lateral to the water mains to receive water. The houses have internal piping supplying water to each fixture, which resembles the leaf. Figure 5.1.B below shows a schematic of the Flint water system illustrating the tree like nature of a water distribution system.

Figure 5.1.B: Schematic figure of the distribution system in Flint, Michigan. Note that there is only one source of water, and all properties served by the distributions system received the same water.



A variety of piping materials are used to convey water in the mains. Most water systems in the US have main distribution pipes that are constructed of ductile iron, cast iron, asbestos cement, mortar lined pipe, or PVC. For water pipes, the use of cast iron pipes dates back to Europe in the 1300's and galvanized steel back to the 1940's. Ductile iron piping dates back to 1955 and dominated the US market for water mains by the 1970's.

The water mains are connected to individual users' systems by service laterals. Lead laterals were commonly used in the northeastern United States until the 1950's when installations ceased and were required by an 1897 ordinance in Flint. The usage of lead pig tails for joining cast iron continued until they were prohibited in 1988 by the Lead Contamination Control Act. The laterals in Flint Michigan were

constructed of a mix of lead pipe, galvanized steel pipe, and copper pipe. The negative impacts of lead water poisoning have been well known since the time of the Romans, yet lead containing components are present in many water systems across the US.

Piping inside of structures is commonly made from lead, copper, or galvanized steel. Therefore, not only would metal have suffered from the impacts of corrosion outside of the homes, the metal pipes would also have suffered from corrosion inside of the homes.

In the US, galvanized piping became common after World War II and is the most common piping within buildings across the world. Copper piping has been displacing galvanized piping in the United States for household plumbing since the 1950's. More recently both plastic piping (PCV, PEX) and copper are common. Each of these types of pipes (with the exception of plastic) is susceptible to corrosion and the potential release of metals from the piping material (hence the reason for the terminology "Lead and Copper Rule" [LCR]). The drinking water chemistry must be managed to maintain the life of metallic pipes and fixtures, to limit or prevent corrosion, and to prevent the release of metals into the drinking water.

5.2 The City of Flint and its Water Distribution System

The first water distribution system in Flint was privately owned and was called the Flint Water Works Company. That company was incorporated in 1883. In 1897, the City of Flint passed an ordinance requiring the use of lead laterals (Masten 2016). The City of Flint purchased the Flint Water Company in 1912.

The Flint Water Treatment Plant (FWTP) was originally constructed in 1917. Flint River water was treated at the FWTP and served as the source of water for the City of Flint until the mid-1960s. From the 1930s, the water from the Flint River was treated using alum coagulation, sand filtration, and chlorination as a disinfectant. The 1917 plant was rated to treat 28 million gallons per a day (mgd). Construction of a new treatment plant for the City of Flint was completed in 1954. At that time the treatment system consisted of prechlorination, coagulation with alum, lime-soda ash softening, recarbonation, filtration, addition of polyphosphate for corrosion control and final chlorination. The treatment plant was rated for 59 mgd with a maximum capacity of 86 mgd.

Flint's population peaked exceeding 200,000 in the 1960's (Davis et al. 2016), driving the need for additional water supply sources. To expand its water supply, the City of Flint began purchasing treated water from Detroit Water and Sewage Department (DWSD) in 1967, and at that time converted the FWTP into standby operation. The primary purpose for the switch over to the DWSD was to ensure that there was sufficient water for the growing population of the City of Flint, and to improve treated water quality. The water provided by DWSD was treated lake water from Lake Huron.

Following the switch to DWSD water, the City of Flint water treatment system, known as the Flint Water Service Center (FWSC), was maintained as a backup water treatment facility. The FWSC system was put into service a few days a year, however, the treated water was not blended into the distribution, but was instead returned back into the Flint River under a National Pollution Discharge Elimination System (NPDES) permit. By 2014, the population of the city had declined to less 100,000 people with a 20 percent drop occurring since the year 2000. Water demand in the City accordingly decreased due a reduction in population and industrial needs.

DWSD implemented modern corrosion control via orthophosphate in their water starting in 1996. Corrosion control studies were performed on the DWSD water in the 1990s, which included “a desktop study, a pipe loop study, and pilot distribution system testing, including water quality parameter testing” (GLWA, 2016). Those corrosion control studies were used to determine the required properties of the treated water to minimize corrosion, which included establishing a minimum orthophosphates dose of 0.9 mg/L (GLWA, 2016). At the time of the 2014 switchover from DWSD to Flint River water, the distribution systems in Flint had been receiving water with optimized corrosion control (pH control and orthophosphate addition) for almost two decades.

The high chloride concentrations in the Flint River resulted from a variety of sources including storage in Holloway Reservoir (evaporation and concentration), industrial and agricultural discharges, and runoff of salt used in wintertime road deicing. These conditions were well known prior to the switch to the Flint River in 2014 (USGS 1963). The concentrations of chlorides in the distributed water were further increased 25 to 100 percent by the use of ferric chloride, as a coagulant at the water treatment plant (Masten 2016). The coagulant choice and dosing rates are critical water system design/operational parameters, that should have been corrected by the system engineers (LAN and later Veolia).

The high concentrations of chloride in the water combined with the low concentrations of sulfate resulted in high values on the well-known corrosion index, the Chloride-Sulfate Mass Ratio (CSMR). The CSMR values, which LAN should have identified before the switch in 2014 and which Veolia should have identified later (in February 2015) put the system at corrosion risk categories of *significant concern* to *serious concern (see Figure 7.2.A)*. The data required to perform the CSMR calculation was readily available to the engineers involved, and consists of commonly measured water quality parameters. The highly corrosive water was present throughout the entire distribution system as there was only one water source suppling the City of Flint. This water compromised the integrity of the piping materials, and shortened the life of the steel and copper piping, and that of the brass fixtures and fittings.

The corrosivity of the Flint River water was further exacerbated when the engineers failed to recommend or take steps to utilize any form of corrosion control, such as, pH control and/or orthophosphate addition. This corrosivity was compounded by the addition of Ferric Chloride as recommended by the engineering firms. Due to the failure to make these recommendations, the City ultimately provided water without any form of corrosion control and unstable water quality which caused immediate degradation of the existing lead phosphate scales. No corrosion control was provided during the entire period of operation using the Flint River water as its source. Veolia recommended increasing the dosing of ferric chloride, which resulted in an increasing value of the CSMR making the water even more corrosive. Rather, if Veolia had recommended that Flint stop adding ferric chloride, corrosion would have decreased.

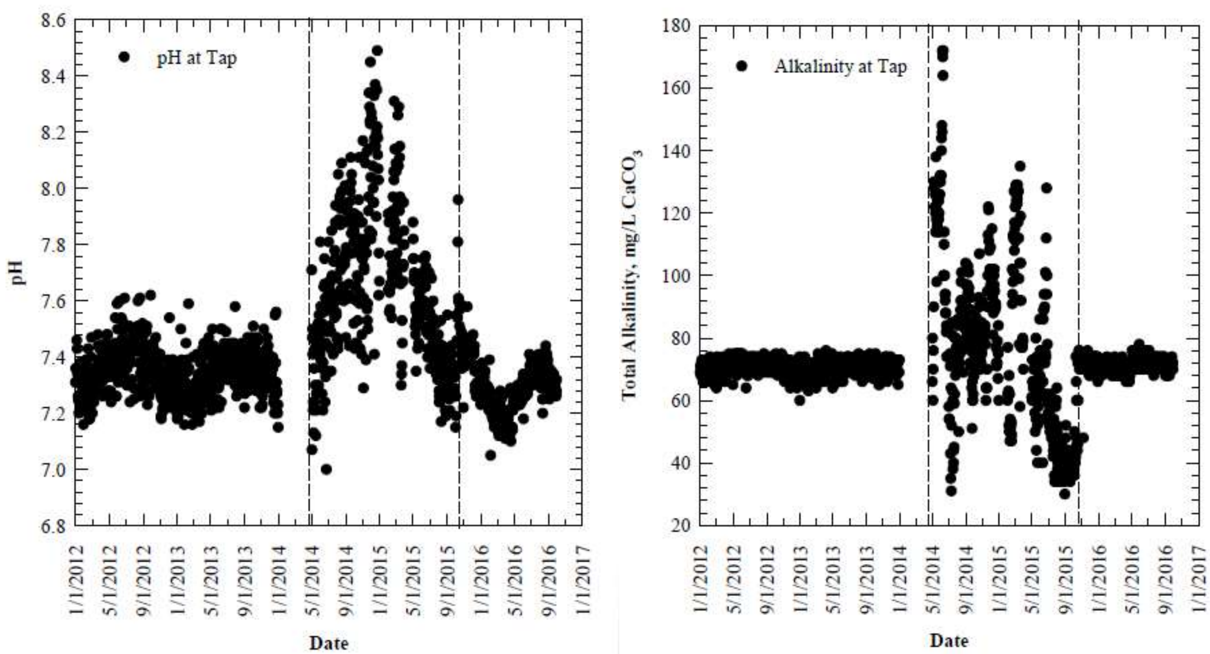
When alum was in use to treat Flint River water in the 50’s and 60’s, the CSMR was 0.35 (see Section 7, USGS 1963), whereas the CSMR increased to between 2.8 and 3.8 during the Flint Water Crisis. When the increased dosage of ferric chloride was in use, in accordance with the Veolia and LAN recommendations, the CSMR increased dramatically to the point of putting the water at serious risk of corrosion (Figure 7.3.A).

This corrosive water provided from the Flint River increased the effective corrosion rate by upwards of an order of magnitude (10 times more) when compared with the DWSD water that was provided to Flint prior to the switch in 2014 (Edwards 2015). This increased corrosivity was obvious given the magnitude of the increase in the CSMR in a low alkalinity water (as was present after softening of the Flint River water).

Thus, had Veolia or LAN simply recommended that Flint switch back to alum, as was used as a coagulant for nearly 50 years prior to1967, the CSMR would have decreased from 3.8 to 0.35, which would have resulted in a substantial reduction in the rate of iron and lead corrosion. Today the CSMR in Flint, which is again supplied with DWSD water, is approximately 0.5 (or less) with an alkalinity of 75 mg/l as $CaCO_3$ (DWSD 2019, Consumer Confidence Report). The DWSD is sourced from Lake Huron, which is naturally less corrosive. None the less, is the DWSD water is treated for corrosion control with orthophosphate (the dosage of which is now further increased by the City of Flint).

One of the essential aspects of controlling corrosion in water systems is providing stable water chemistry conditions. The water in the distribution system attempts to establish equilibrium with the various plumbing components and particularly the surface scales. Consequently, stable conditions help establish the formation of scales and rapidly changing or variable conditions tend to destroy the protective scales. During the Flint Water Crisis, they system demonstrated high highly variable conditions for two critical water quality parameters, pH and alkalinity.

Figures 5.2.B and 5.2.C: pH (left) and alkalinity (right) of the treated water supplied in Flint from 2012-2017. The vertical dashed lines show the period the system was supplied with Flint River water from approximately May 2014-October 2015. Note the dramatic variability in both parameters during operation on the Flint River water as compared with the DWSD periods (January 2012-May 2014 and October 2015-October 2016). As can be seen in the plot on the right, alkalinity was variable and was at low levels for multiple periods during operation on the Flint River water.



Such variability is known to be a principal cause of the destabilization of phosphate scales which releases metals into the water and can allow for enhanced corrosion. This fluctuation can greatly accelerate corrosion, can be a driving factor in the progression of pinhole leaks in copper, and can cause lead scale detachment and migration.

The engineering consultants clearly lacked the knowledge needed regarding the required corrosion control strategies. As a result, the City of Flint was subjected to corrosive water that damaged plumbing systems

and exposed the residents to high concentrations of lead. Much of these problems could have been avoided by implementation of proper corrosion control.

During 2005-2011 LCR sampling, while the City of Flint operated on DWSD water, the distribution system in Flint consistently reported lead sample results that were below the Action Level as specified in the Lead and Copper Rule (LCR). In fact, during the three LCR sampling events which occurred (2005, 2008, 2011) Flint's lead and copper sampling failed to locate a single home in the City, which had lead concentrations in excess of the 15 µg/L action level. Further, the LCR lead sampling in 2008 and 2011 did not detect a single sample above the detection limit reported (2 µg/L) (EGLE0002604).

When the water source was switched to the Flint River in 2014, the lead concentrations measured in the LCR sampling began to rise. The Flint River was a water source with high chlorides, and a high chloride to sulfate mass ratio (CSMR) indicating it had a high risk for corrosion, but it was not treated for corrosion control. During the summer of 2015, the City of Flint reported lead concentrations below the LCR 90th percentile action level of 15 ppb.

In contrast to that data, Professor Marc Edwards and his team at Virginia Tech directed sampling in Flint in August 2015 that found detectible levels of lead in 85 percent of the first draw samples they collected from residences. The comprehensive sampling performed by the Edwards team found that Flint's housing actually had water samples with a 90th percentile lead concentration of 26.6 µg/L, over 75 percent above the regulated action level (Pieper et al. 2017; Pieper et al. 2018).

On June 24, 2015, the U.S. EPA indeed concluded that "galvanic corrosion" had increased as a result of the chloride in the Flint River water and the City's continued use of ferric chloride (Del Toral 2015, emphasis added):

In addition, following the switch to using the Flint River, the City of Flint began adding ferric chloride, a coagulant used to improve the removal of organic matter, as part of the strategy to reduce the TTHM levels. Studies have shown that an increase in the ***chloride-to-sulfate*** *mass ratio in the water can adversely affect lead levels by* ***increasing the galvanic corrosion of lead in the plumbing network.***

The causes for this dramatic difference in concentrations between the LCR data and Virginia Tech data is discussed in the LCR review presented in Section 9.

Extensive lead contamination was identified in the water at a Flint residence by the Virginia Tech team during the Flint Water Crisis. They performed comprehensive testing during the Flint Water Crisis and identified lead concentrations as high as 13,200 µg/L at the tap. That concentration is 880 times higher than the action level defined in the LCR regulations (Pieper et al. 2017). In fact, one eighth of Virginia Tech samples from the test sites contained lead concentrations in the drinking water that exceeded the EPA threshold for hazardous waste of 5000 µg/L (Pieper et al. 2017) indicating a serious concern for anyone who consumed that water.

The Flint River presents a number of challenges with regards to treatment and corrosion control. Evidence for these challenges dates back to at least the 1950's when the City previously operated on the Flint River. During that period polyphosphates were added to the water (Masten, 2016; USGS 1963). Polyphosphates were characterized as corrosion control but are indeed solely used to mitigate the aesthetic impacts resulting from corrosion in the iron-based piping systems (i.e. red water), but do not control or limit corrosion. In fact, the use of polyphosphate can increase corrosion. An assessment of the Flint River

performed by the Michigan Department of Natural Resources in 2001 identified that the Flint River had chlorides present. Sources providing chlorides to the river included discharges from industry (regulated and unregulated) and roadway runoff (i.e. road salting) (Leonardi and Gruhn, 2001).

Also, as highlighted in the 2002 treatability study on the Flint River water that was performed by AB&H, the water had a number of challenging properties that made the Flint River water more difficult to treat. Examples of those challenges included high and seasonally variable hardness, high organic matter concentrations, and high disinfection byproduct formation potential (AB&H 2002). A 1998 report by the Snell Environmental Group (SEG) evaluated the modifications and upgrades that were needed at the Flint Water Treatment Plant to treat Flint River Water (SEG 1998).

Most of the issues identified by SEG in 1998, remained when the plant was placed into fulltime service on Flint River water in 2014. The SEG report identified the need for phosphate-based corrosion control equipment, concluding that equipment to provide a 1-2 mg/L dosing of PO_4 (SEG 1998 p. 3-12) and a chloramine dosing system to supply a residual disinfectant for the distribution system (SEG 1998 p. 3-16) was required.

The Flint River was a challenging water source to treat, and was known to have corrosion issues dating back at least to its use in 1950s. As is discussed at length in Section 6 of this report, a simple reading of the existing reports and conducting a desktop analysis of the corrosiveness of the Flint River water would have indicated that there were high risks for corrosion with the treated Flint River. These issues should have been identified and addressed via a corrosion control study prior to the change over to the Flint River water. These issues should have also been addressed when LAN and Veolia worked on troubleshooting the Flint issues in 2014-2015.

5.3 Residential Plumbing in Flint and Lead

A large proportion of the homes in Flint were built between 1897 and 1942, and had lead and galvanized steel service laterals (Goovaerts 2017c). Service laterals are the pipes that connect each house to the water mains in the street that supply water throughout the city. The laterals consist of two components, a public owned portion, upstream of the water meter, and a privately owned portion downstream of the water meter (on the residence side). As a result of the Flint Water Crisis, a program was undertaken to inspect and replace the lead and galvanized laterals. More than 25,000 publicly owned laterals have been inspected in Flint and over 9,500 of those laterals have been replaced as of May of 2019 (https://www.cityofflint.com/gettheleadout/ accessed June 16, 2020).

A second source of lead in Flint is high leaded solder used to join copper pipes. Over 99 percent of residential structures in Flint were constructed prior to 1986 (FlintGIS review of property records in 2016; Goovaerts 2017a, Goovaerts 2017b, Goovaerts 2017c). 1986 was a critical date as it relates to lead in plumbing systems. In 1986, the Safe Drinking Water Act was amended to prohibit the use of leaded solder (effective June 1988). Based on the age of the residences in Flint, effectively all structures that contain copper plumbing systems likely contain leaded solder.

The third source of leaded plumbing components are high-lead brasses. The 1986 Safe Drinking Water Act amendments allowed brass to contain up to 8 percent lead. Brass fixtures installed prior to June 1988 could contain even higher concentrations of lead. In 2011, the Federal Regulations were revised to restrict brass lead concentrations to a maximum of 0.25 percent (effective 2014). Brass is one of the most prevalent metals in contact with drinking water within home plumbing systems, which include the following angle-stops, shower/bath mixing valves, and faucets. Due to the age of the residences in Flint, most residences have fixtures with high-lead brass predating the 2014 regulations. The City of Flint switch to the Flint River water source in the year 2014, which suggests essentially all brass fixtures in Flint were high-lead at the time of the Flint Water Crisis.

The fourth source of lead in residential water in Flint is the lead contained in pipe scales inside of the residential plumbing. These scales are known to form inside of the various piping materials used in Flint, such as, galvanized steel, copper, and plastic. When the water was switched to the Flint River in 2014, the established pipe scales were exposed to rapid changes in water quality and no orthophosphate corrosion control, which caused deterioration of the scales. Under these conditions, the scales dissolve and/or are dislodged from the pipe surface. As an example of this source, the “resident zero” house profiled in Pieper et al. 2017 documented that the lead containing scales on the galvanized service line (located downstream of the lead service line) were a major contributor to the lead concentrations measured in this house, which had been plumbed with PVC plastic pipe.

In summary, essentially every residence in Flint Michigan contains plumbing components, which contain high levels of lead. As is discussed at length in this report, each of these lead containing components were impacted by the corrosive water from the Flint River and contributed to the exposure of the residents of Flint to high concentrations of lead.

5.4 Flint's Planned Transition to KWA and Interim Transition to the Flint River

Following the switch to DWSD water in the 1960's, the City of Flint water treatment plant saw extremely limited use. The treatment plant was brought online a couple of days a year to confirm that the equipment was "operational." During that period, water was taken from the Flint River, treated, and returned to the Flint River without any effort to meet water quality standards or to either produce consistent or reliable operations. Transitioning the Flint Water Treatment Plant to return to fulltime use was a major undertaking due to the decades of limited use and inadequate upkeep, a lack of modernization to meet current standards, a lack of system controls, and a lack of experienced operators.

In 2013, the City of Flint entered into an agreement with the newly formed Karegnondi Water Authority (KWA). The plan was for the Flint Water Treatment Plant to be put into service treating Lake Huron water once the new KWA pipeline was completed. This decision was made with the goal of reducing the costs of treated water for the City, and was made by the Governor's appointed Emergency Manager who was the sole decision maker for the City.

While the KWA pipeline was being constructed, the City of Flint had a choice of continuing to purchase water from DWSD, which provided treated water from Lake Huron, or treat Flint River water through their own treatment system (which had seen only limited use since the 1960s). Following the decision to switch to KWA water, a series of failed negotiations occurred between the City of Flint and DWSD regarding continued supply until the pipeline was constructed. Ultimately, the emergency manager made the decision to abandon the DWSD connection and terminate the agreement effective April 2014 (Davis et al. 2016). The City of Flint chose to treat Flint River water to serve as the City's only drinking water source.

The City and its consultant LAN pressed the City's treatment plant into operation with no trial test period to prove either operability or the ability to produce a suitable quality drinking water. This failure cannot be forgiven as this was the last opportunity that LAN had to avoid the Flint Water Crisis.

At that time, the City had available to them a number of reports regarding the switch to treating Flint River water. These reports included a treatability study performed by AB&H in 2002, a treatment plant rehabilitation study performed by Snell Environmental Group (SEG) in 1998, and a capacity analysis performed by LAN and Rowe in 2011. As was clearly identified in these reports, the plant needed a number of improvements to provide safe and reliable operation and the production of safe drinking water.

5.5 The April 2014 Switch and the Flint Water Crisis

At the end of April 2014, the Flint Water Treatment Plant was prematurely pressed into full time service treating Flint River water. Operations reports from May 2014 (shortly after startup) indicate that the system had a long series of deficiencies and projects that were never addressed. At the beginning of operations, the chemical treatment stocks were woefully inadequate for full time, full scale operation with only small amounts on hand.

All large municipal water treatment plants are operated via some form of a Supervisory Control and Data Acquisition (SCADA). The SCADA system controls equipment, processes, and data monitoring. In May 2014, the treatment plant was providing water to the City, yet upgrades for the SCADA system were out for bid. The newly installed equipment was not integrated into the SCADA system. Critical system operation monitoring equipment, such as, chlorine monitors, were not installed when the plant was started up. It is obvious that the switch over should have been postponed given these inherent deficiencies and the undertrained and under qualified operators and the resultant Flint Water Crisis.

At start-up, the system had neither corrosion-control facilities or an Optimized Corrosion Control Treatment evaluation (OCCT) in place as is required by the LCR, nor sufficient expertise within the City staff to develop one (Masten 2016, USEPA 2016a). A functional corrosion control strategy is critically important for all water systems, and even more critical for one that is going through a dramatic change in water quality, such as, would occur with the switch from DWSD lake water to the Flint River water (discussed further in LAN and VNA analyses).

A proper corrosion control study for this type of changeover would have required a couple of years to complete (which was available as the switch over was contemplated in the Rowe report of 2011. Even when the system was taken out service in 2015, it still did not have chemical treatment for corrosion control, such as, an orthophosphate dosing system. As the primary tool in the City's toolbox, the burden fell to the engineering consultants, LAN and Veolia, to steer the City to safety with regards to the corrosion issues.

In summary, the switch to Flint River water was made in a system that had critical design errors, inadequate or malfunctioning equipment, no corrosion control equipment, no OCCT, and did not have the trained staff or the chemicals required for treatment. Shortly after the changeover, these shortcomings and the misguided treatment process manifested in a variety of issues throughout the water system. These issues included corrosive water, biological growth in the distribution system, and inadequate residual disinfectant concentrations throughout the system. These issues should have been obvious to a water treatment consultant, like Veolia.

As was revealed by the work of Professor Marc Edwards' team from Virginia Tech, this corrosive water produced by the Flint Water Treatment Plant damaged piping systems throughout the City and exposed the residents of Flint to high concentrations of lead (Pieper, Tang and Edwards, 2017;flintwaterstudy.com September 29, 2015 *Research Update*).

6 The Professional Responsibilities of Engineering Firms Like LAN and Veolia

6.1 Professional Engineers and their Standard of Care

It is standard engineering practice that engineering consultants provide municipalities, such as, the City of Flint, with state-of-the-art engineering science and technology. Environmental engineering consultants ensure that the client maintains an appropriate measure of compliance with environmental regulations, such as, the Drinking Water Standards. An environmental engineering consultant needs to have the scientific knowledge and technical expertise to conduct thorough environmental assessments.

Environmental engineering consultants conduct both field and desk-based research, and will develop completed and detailed scientific reports. The reports should be written in a manner that can be understood by non-technical people. Their research will identify whether water chemistry and contaminants will have an adverse impact on people, materials or the environment. They will interpret data, including detailed in-depth assessment of the data, sometimes using software-modelling packages to see whether existing contamination can be managed to meet current regulations and to minimize impacts to human health.

The Standard of Care for engineers is simple and straight forward, namely: ordinary and reasonable skill (care) usually exercised by one in the profession, on the same type or project, at the same time and in the same place, under similar circumstances and conditions. What does that mean? It means that an engineer is obligated to meet the same quality of work and best engineering judgement, that is required of the profession. Did the engineering consultants, LAN and Veolia, meet this standard in the services they provided to Flint? In a word, NO.

Professional environmental engineers also perform under the ethics guidance of the American Society of Civil Engineers (ASCE) and the National Society of Professional Engineers (NSPE). The foremost guidance of both of these ethics code is shown in the NSPE Pledge below:

> **I pledge:**
> *To give the utmost of performance;*
> *To participate in none but honest enterprise;*
> *To live and work according to the laws of man and the highest standards of professional conduct;*
> *To place service before profit, the honor and standing of the profession before personal advantage, and the public welfare above all other considerations.*

Clearly, engineering consultants are held to a standard that requires putting the public welfare first. The expert report by Dr. Gardoni provides an in-depth overview ethical and standard of care obligations of LAN and VNA. The specific technical failures of LAN and Veolia in the Flint Water Crisis as they apply to engineering Standard are described in this report.

6.2 LAN and its Work for the City of Flint

LAN has a long history of involvement with the water system in Flint dating back to at least 1997 and the work performed of AB&H. Unfortunately, LAN's involvement over the years directly contributed to, and in many cases directly caused, the problems experienced with the Flint water system. LAN performed the engineering analysis to determine the minimum required to bring the Flint Water Treatment Plant into full time service using the Flint River water as the source as early as 2013.

LAN staff, such as, Mr. Green, Mr. Matta and Mr. Hansen worked on this Flint system dating back until at least the late 1990's. Starting in 2009, LAN produced or participated in the following five reports and documents for the City of Flint.

- 2009, September: *Preliminary Engineering report Lake Huron Water Supply Karegnondi Water Authority*
- 2011, July: *Analysis of the Flint River as a Permanent Water Supply for the City of Flint*
- 2013, June: *Memo and proposed scope; Re: Flint Water Treatment Plant Rehabilitation – Phase-II*
- 2014, November: *Operational Evaluation Report, City of Flint: Trihalomethane Formation Concern, Draft*
- 2015, February: *Operational Evaluation Report, City of Flint: Trihalomethane Formation Concern, Final*
- 2015, August: *Operational Evaluation Report, City of Flint: Trihalomethane Formation Concern, In Response to May 2015 Sample Results, Final*

LAN (along with another engineering firm, ROWE) participated in a 2009 study evaluating the development of a new KWA supply to service the City of Flint, Genesee County, Lapeer County and Sanilac County. The study performed a cost analysis centered on the evaluation of whether to continue utilizing the Detroit system (DWSD) versus installing a new pipe supplying water from Lake Huron. The report argued that the KWA agreement ultimately provided cheaper water than DWSD. The LAN conclusion/recommendation was proven to be wrong as documented by the engineering firm of Tucker, Young, Jackson and Tull hired by Michigan Treasurer Dillon in February of 2013 to address this issue.

In 2013, LAN was contracted with the City of Flint under a sole source agreement to provide the City with the engineering knowledge and guidance they lacked. Under this contract LAN was performing the engineering evaluations to put the Water Treatment Plant into full-service operation treating Flint River water.

LAN led the City of Flint down a path that ultimately allowed for unsafe and highly corrosive water to be distributed throughout the community. This water resulted in permanent damage to the piping systems and impacted the health of the residents of Flint. LAN continued to provide engineering services under a series of contract extensions and scope modifications through 2015. LAN was also contracted to address an issue with disinfection byproducts following the switch to the Flint River. The work performed by

LAN through their involvements ultimately resulted in a complete loss of consumer confidence and faith in their water system.

Ample information was available to LAN which should have allowed LAN to see that changing to the Flint River water presented unacceptable risks due to the excessively corrosive water. These issues should have been immediately apparent to LAN. The use of Flint River water without corrosion control caused damage to the piping system and leaching of lead into the water.

LAN had an ethical and professional obligation to provide safe drinking water to the City of Flint. LAN failed in these core obligations, ignoring the obvious outcomes to the system for which LAN was providing the technical expertise to the City to bring the treatment plant into service. Once the system went into service, and these problems arose, LAN had an obligation to honestly inform the public and regulators about the risks to human health and to plumbing systems throughout the City. LAN failed in these obligations and ultimately failed to meet the Standard of Care required of all engineers. Details on the failure of LAN to meet the Standard of Care are discussed in Section 8.

6.3 Veolia and its Work for the City of Flint

Veolia North America (Veolia) is the North American arm of Veolia Group, which provides services for a wide range of industries including utilities, municipal services, transportation, energy, mining, and manufacturing. On Veolia's website they claim that "our experts deliver the water treatment solutions that improve the quality of people's lives in communities around the world" and "communities trust us to ensure their safety and to meet the most stringent performance standards" (https://www.veoliawatertechnologies.com/en/veolia-water-technologies, accessed 6/2020).

In January 2015, the City of Flint issued a request for proposals to address the City's ongoing water quality issues. In its request for proposals, the City stated that it was "…seeking a consultant to review and evaluate the water treatment process and distribution system, provide recommendations to maintain compliance with both state and federal agencies, and assist in implementing accepted recommendations" (Nicholas 2019, Exhibit 7, Veolia 006438).

Veolia responded to that RFP on January 29th, 2015. As described in their response to the RFP, Veolia stated that "Veolia would mobilize a team of experts, including our two prominent water SMEs, from our corporate Technical Services Group [an in-house team of technical and management experts that support the company's projects and operations throughout North America]" (Nicholas 2019, Exhibit 7, Veolia 003120). The lead technical staff provided by Veolia were Mr. Marvin Gnagy, P.E. and Mr. Theping Chen, P.E.. The VNA proposal stated Mr. Gnagy had more than 37 years of experience in "…water quality management experience, and is a certified Water Operator in Ohio and a registered Professional Engineer" (Veolia 006486). Mr. Chen was described as having "…close to 30 years of water engineering, operation, and research experience, and he spent 15 years as a water consulting engineer in Michigan and is a registered Professional Engineer in the State of Michigan" (Nicholas 2019, Exhibit 7, Veolia 006487).

Veolia stressed that it understood the significance and urgency of the water quality issues facing the City: David Gadis, the Vice President of Veolia's Municipal and Commercial Business, stated "we understand the frustration and urgency in Flint," and that Veolia was "honored to support your community with our technical expertise so that together we can ensure water quality for the people of the city of Flint." Veolia claimed to have "…extensive experience handling challenging river water sources, reducing leaks and contaminants and in managing discolored water," and that Veolia "look[s] forward to helping Flint's team find ways to address and improve the city's drinking water operation." [Accessed 6/2/2020: https://www.cityofflint.com/2015/02/10/flint-hires-international-urban-water-experts-of-veolia-north-america-to-assess-citys-water-issues/].

The contract with Veolia for their services was signed on February 4th, 2015 and included a not to exceed contract amount of $40,000. The scope of work in the contact was extensive and was to "…provide consulting and related services to [the City of Flint] in connection with the project as outlined in Contractor's Proposal dated January 29, 2015" (City of Flint, 2015). In the Veolia proposal, they stated that they will be providing a broad scope of services (Nicholas 2019, Exhibit 7, Veolia 006489):

In order to respond to the immediate needs of your defined scope of work, we anticipate mobilizing a team of technical, operations, maintenance and communication SMEs to: calibrate daily water quality samples with the City's hydraulic model; refine the operation strategies for the plant and distribution systems; coordinate daily efforts across plant, operation and maintenance staff; and to alleviate continued concerns from the public through a public communications process.

Veolia then went on further describing their long-term approach (Nicholas Exhibit 7, Veolia 006489):

For the longer-term type of approach, Veolia would set up a single lump sum price for the study, implementation and long term services after review and discussion with the city and selecting your preferred approach – the [Peer Performance Solutions] approach or the contact [Operations and Maintenance] approach.

Veolia's Peer Performance Solutions (PPS) was a business model which was "…a form of consulting, but instead of being paid upfront, [Veolia] take[s] the risk for the savings and then we share in that savings" (Nasuta, 2019, p. 37 L20-23). Under the PPS structure, Veolia develops and implements strategies to address issues that the water utility has. Veolia would be paid based on the achievement of performance metrics. Under an Operations and Maintenance (O&M) approach, Veolia would provide private operations for the utility, typically taking over the role of the City's operators. Both of these structures suggest that Veolia viewed their work in Flint as a gateway to a much larger project. The business development department for Veolia later admitted that they were trying to utilize this project to gain more work from Flint (Nicholas 2019, p. 768 L 22- p.269 L 5)

[Question] While you were performing these services in Flint, you were trying to upsell the city to a much larger contract that would have brough in more than a million dollars a year for Veolia; is that correct?
…
[Answer, Nicholas] Correct

Members of the business development team at Veolia clearly viewed the contract in Flint as a means to achieve much larger contracts for services in Flint. In later describing the project, Veolia's Robert Nicholas wrote "we saw this as a paid sales effort so not as concerned about the dollar value" (Nicholas 2019, Exhibit 24, p. 1).

Veolia agreed to help the City of Flint with its water system problems and assigned two professional engineers, Marvin Gnagy and Depin (Theping) Chen, to that project. Those engineers were bound by the professional and ethical obligations of engineers. Veolia performed broad analyses of the water system and both in their presentations and reports they made statements that the water treatment plant and distribution system were in compliance with state and federal water quality regulations. In completing their work, the Veolia engineers both downplayed the severity of the problems in Flint and completely failed to address the presence of other problems (such as the lack of *any* form of corrosion control in the distribution system, the presence of highly corrosive water, the human health and property damage risks associated with corrosive water, and the specific risk of lead leaching).

Veolia was aware that corrosion control was needed in Flint, but in their February and March reports, they never stressed to the City, the public, or the regulators, the necessity or urgency of that requirement. Veolia never completed the standard chloride sulfate mass ratio ("CSMR") analysis used to assess the corrosivity of the water, even though the data needed was readily available in Veolia's own project documents. Had Veolia performed that CSMR calculation, the results would have shown that the water was a concern for corrosion and posed a threat to human health and property. The engineers from Veolia were aware that the best engineering solution was to return to DWSD water, but in their February and March reports they failed to present that option in their presentations and reports. The engineers from

Veolia did not meet the Standard of Care and failed the public by allowing continued destruction of the piping systems and exposure of the residents to harmful concentrations of lead.

Contrary to Veolia's professional and ethical obligations, Veolia never issued a report stating that the City of Flint needed to perform the EPA Lead and Copper Rule mandated study to develop a comprehensive engineering study to develop the Optimal Corrosion Control Treatment (OCCT) program for a given water quality (USEPA 2016a). Nor was there a single Veolia report that called for either blending of the treated Flint River water with the DWSD water, the immediate installation of corrosion inhibitor injection, or an immediate switch back to the DWSD water supply.

Veolia professional staff should have recognized the shortcomings of the training of the Flint water treatment personnel. No such documentation of their concerns exists in writing.

As correctly pointed out by Mr. Ringstad in a question to Mr. Schock in his deposition (Schock 2020, Vol I p.166 L12-17)

Q: And in that time frame, were you just a phone call or an e-mail away, you know, for City of Flint or for DEQ to reach out to you?

A. Yeah, that's the way it always works

LAN or Veolia could have reached out as easily when (or if) they realized that they needed assistance, but did neither did so.

As described by Mr. Glasgow from the operations arm of the Flint Water Treatment Plant, Veolia did not provide adequate warnings about the lack of corrosion control, and that the City would have followed their advice if they had. Had Veolia provided the City with the information regarding corrosion risks, the City could have taken action much sooner to address the issue. Mr. Glasgow stated in deposition (Glasgow 2020, p. 649 L21-p.650 L7):

[Question] …isn't it clear that Veolia did not give you the kind of warning you would have expected an expert engineer to give about the impact of not having corrosion control?

[Answer, Glasgow]. I can agree with that.

Mr. Glasgow then went on to describe what they would have done with that type of information from Veolia (Glasgow 2020, P. 649 L2-8):

[Question] If you had gotten that kind of warning in any way, shape, or form, whether orally or by a presentation, would you have done anything with it?

[Answer, Glasgow]. Yes, I would have.

[Question] What would your normal practice have been?

[Answer, Glasgow]. Normal practice would be to grab my supervisor and have a frank discussion with them about what needs to be done.

6.4 Root Cause Analysis (RCA)

A root cause analysis (RCA) is procedure for determining the root cause of a failure or problem. This concept is commonly used in a wide variety of fields ranging from industrial accidents, aviation disasters, and in medical mistakes.

The primary goal of an RCA analysis can be summarized as follows:

- What happened
- How did it happen
- Why did it happen
- Develop actions to address the problem and prevent the future recurrence of the problem

The RCA provides a framework for determining the root issue from which the failure derives. In a generalized form, the RCA analysis employs the following basic steps:

- Define the problem
- Gather the available information and data
- Identify all issues and events that contributed to the problem
- Determine the root cause
- Develop recommendations to prevent the reoccurrence of the problem
- Implement the identified solutions

Stated another way, in the words of Veolia's Fahey (Fahey 2019, p. 99 L6-13):

A root cause analysis is a process which one would go through to determine… why something occurred… One of the most common is the five why approach, where if you ask why five times, you'll eventually get to a root cause.

A detailed description of Veolia's RCA procedure is presented in the internal Veolia memo titled *Environmental Incident Investigation, Root Cause Analysis and Corrective Action* (Hagerty, 2019, Exhibit 16). Based on the presence of internal guidance documents such as this, Veolia routinely provides RCA services for their various projects.

In the context of the engineering firms involved in Flint, the RCA analysis provided an ideal framework to determine the cause of the problems, which were occurring after the water switch. As an example, the firms could have performed an RCA analysis to address the reports of red water and pipe breaks in the distribution system. This analysis would have rapidly identified issues with the corrosivity of the water and shed light on the lack of corrosion control. In a similar context, investigations into the TTHM issues via an RCA would have led to a series of investigations identifying problems with the disinfectant being used and the biological growth within the distribution piping systems. This biological growth within the piping system was a contributor to the corrosion issues discussed below that should have been addressed by an RCA by both LAN and Veolia.

7 Corrosion and Corrosion Control Technology in Water Distribution Systems

7.1 Corrosion and why it matters

7.1.1 Overview

Research into the causes and mechanisms of corrosion has a history of over 200 years. In the early 1800s the first understandings that corrosion was an electrochemical process were developed. Substantial progress on understanding the root processes associated with corrosion was made in the 1910s and 1920s. As it pertains to corrosion in water systems, Langelier performed some of the seminal work in the 1930s working to understand the role of carbonate chemistries and the corrosion of cast iron pipes (his studies included water from the Detroit Water and Sewer Department). In the 1950s and 1960s, significant progress was made on understanding the role of scales and electrochemistry interactions. In the 1970s, the rate of progress in the field of corrosion science accelerated and led to our modern understanding of corrosion.

Corrosion in water conveyances has been a critical issue since the advent of water systems dating back to the Roman's use of lead pipe. Generally, the metals used in copper and steel pipes are inherently unstable (thermodynamically) in the presence of water and will dissolve and form metal oxides via corrosion when in contact with water. Tools for assessing the chemistry and corrosivity of water were first developed in the 1930s and have improved since then. The Langelier Saturation Index (LSI), discussed below, was one of the initial tools used to assess corrosivity. More recently identified tools, including the chloride-to-sulfate mass ratio (CSMR), were known to be more appropriate measures of corrosivity for iron and lead which was relevant for the Flint system. Most water purveyors spend significant resources to make chemistry changes to the produced water that increases stability and decreases corrosion in the distribution and household piping system.

7.1.2 Introduction to types of metal corrosion and particulate lead issues

There are a variety of different issues with plumbing systems that are relevant for understanding what occurred in Flint during the use of the Flint River water. The following sections provide an overview of some of the typical types of corrosion. An overview of sources and role of particulate lead is also presented therein.

7.1.3 Dissimilar Metals Corrosion

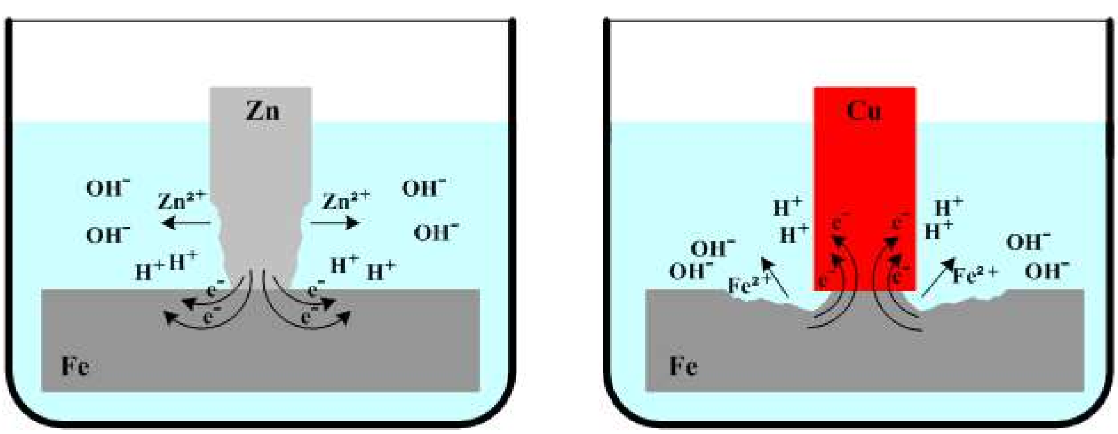
Galvanic corrosion, or dissimilar metals corrosion, refers to electro-chemical interactions between two dissimilar metals. Most household water systems contain dissimilar metals in contact, most commonly steel and brass, but copper-lead solder, lead-brass and iron-copper are also found. This situation sets up a galvanic current and one metal is “sacrificed” in favor of the other. The direction and severity of this galvanic corrosion depends on a number of factors including the electrical potential difference between the two metals, and the composition of the water.

The science of galvanic corrosion is well understood and dates back to Volta in the early 1800’s. Essentially, galvanic corrosion (also called ' dissimilar metal corrosion' or 'electrolysis') refers to corrosion induced when two dissimilar materials are coupled in an electrolyte solution (water). In other words, galvanic corrosion occurs when two (or more) dissimilar metals are brought into electrical contact, which includes being submerged in water or buried in damp soil when they are directly connected. In the case of a household plumbing system this electrical contact occurs when filled with water and the metals are directly connected to each other. When a galvanic coupling occurs, one of the metals in the couple is the anode and it corrodes, while the other is the cathode and is protected from corrosion.

Electrode potentials are a relative measure of a metal's tendency to perform as an anode or a cathode in a given electrolyte solution. The more active, or less noble, a metal is the more likely it is to be an anode (positively charged electrode) in an electrolytic environment. The less active, or nobler, a metal is the more likely it is to be the cathode (negatively charged electrode) when in the electrolytic environment.

The electrolyte acts as a conduit for ion migration, allowing metal ions from the anode to move towards the cathode. In the case of the household piping system, the reality is that the metals simply go into solution (in this case the drinking water). The figure below presents a simplified schematic of the galvanic corrosion cells for galvanized pipe (iron-zinc [Fe-Zn]) and steel to copper/brass (iron-copper [Fe-Cu]).

Figure 7.1.3.A. Schematic diagram of galvanic corrosion in two dissimilar metals systems. The left figure shows an iron-zinc (Fe-Zn) coupling where the zinc is corroding to protect the iron. The right figure shows an iron-copper (Fe-Cu) where the iron is corroding to protect the copper. (adapted from Dr. Kopeliovich’s article on substech.com).



7.1.4 Galvanized Steel Corrosion

Galvanized steel is coated with a protective plating of molten zinc. The coating typically consists primarily of zinc, but can contain other metals in low percentage amounts. The zinc coating is used to provide increased corrosion resistance due to the protection provided by the zinc, which is less noble than the iron (the zinc is sacrificed to protect the iron).

Galvanized plumbing components are also subject to extensive corrosion in saltier or variable alkalinity environments. The corrosion that occurs causes irreparable damage to the pipe. Galvanized plumbing in Flint includes service lines, and household plumbing. The galvanized pipe has been implicated in cases of high lead exposures (McFadden et al. 2011; Clark et al. 2014; Masters and Edwards 2015). Galvanized plumbing became popular following World War II (WWII). Galvanized steel pipe was invented in 1830, and it was used extensively for the rebuilding of Germany after WWII to address red water complaints associated with the use of black iron pipe used in German household plumbing.

Lead concentrations at the tap in homes with galvanized plumbing can remain high even after removal of a lead service line. The galvanized premise plumbing builds up internal iron scales which can trap particulate lead and provide extensive surface area for lead containing scales.

Lead exists as a lessor component of the zinc plating used on galvanized pipes. Lead concentrations in galvanized coatings has been documented ranging as high as two percent (Clark 2015). Lead is released from the zinc coatings during corrosion processes until the coating is fully solubilized. The released lead enters the drinking water and can serve a long-term source of lead in domestic plumbing systems (Clark 2015). That lead can reach the consumers' taps, or can be recaptured downstream in internal pipe scales which can later be released into the drinking water.

Corrosion of steel (carbon steel, stainless, and galvanized) has been studied for many years because of its importance to many aspects of infrastructure. Important aspects of the water system that can result in accelerated steel corrosion include chloride, sulfate, organic carbon, and biofilms. Professor Edwards group at Virginia Tech group measured corrosion rates up to 8.6 times for iron in the treated Flint River water compared with the DWSD water (Edwards 2015). The increased corrosion rates are discussed further in Section 10. These rates were estimated for uniform corrosion and accordingly the rates do not include pitting corrosion (tubercle formation) nor Microbially Induced Corrosion (MIC). Therefore, the actual corrosion rates may have been even higher during the Flint Water Crisis.

7.1.5 Copper Pitting Corrosion

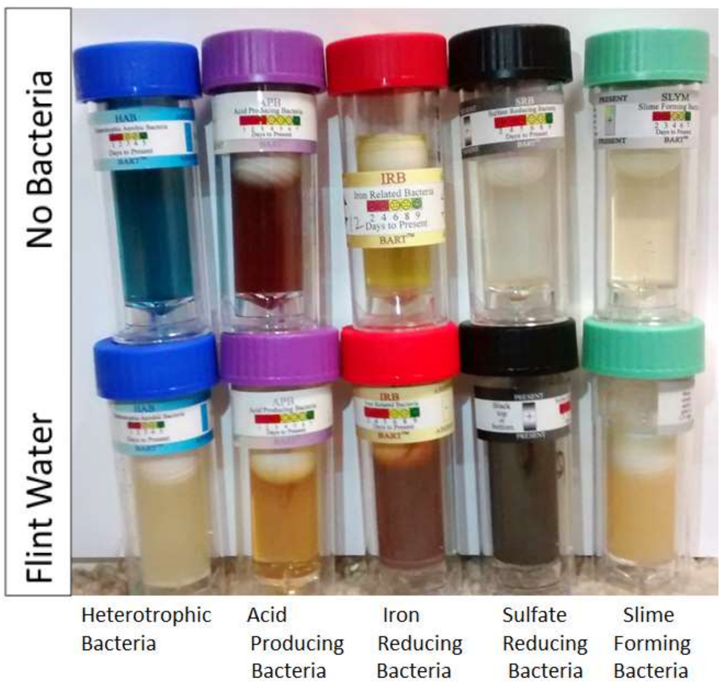
Copper is the most commonly used metal in interior plumbing, as least since the 1950s. Most damage from copper corrosion comes not from uniform corrosion, but from localized penetration of the pipe wall via pits which ultimately result in "pinhole" leaks. Pitting corrosion causes rapid and irreversible degradation of copper pipes. Once a pit initiates in a copper pipe, the pit will continue to corrode and ultimately result in a leak location when the pit penetrates through the side of the pipe. Pitting corrosion is a major concern in systems that support the growth of biofilms inside of the distribution and piping systems. This process, associated with Microbially Induced Corrosion (MIC), tends to occur in water system with high concentrations of available carbon (TOC and AOC) as there is in the Flint River water (the TOC and AOC serve as a food source for the microorganisms), and inadequate or unstable disinfectant residuals (Cantor et al. 2006, Lytle and Shock 2008).

The residual disinfectant, such as, free chlorine or chloramines, will inhibit growth of microorganisms, thereby minimizing MIC. The lack of a disinfectant residual has resulted in the formation of pitting corrosion in over 100,000 homes in southern California (Russell 2016). The conditions during the Flint

Water Crisis subjected copper pipes to water that was corrosive, had high concentrations of available organic carbon, lacked adequate disinfectant residual, and contained substantial amounts of bacteria (the City was required to issue a Boil Water Notice on several occasions during 2014-2015). In other words, Flint presented ideal conditions and opportunity for pitting corrosion to occur.

Professor Edwards and his team from Virginia Tech established that the types of organism commonly associated with MIC were present in the Flint piping system during their work in 2015 (Edwards 2015). Their testing showed the system tested positive for *acid producing bacteria, iron reducing bacteria, sulfate reducing bacteria,* and *slime forming bacteria* as shown in Figure 7.1.5.A.

Figure 7.1.5.A. Results of the BART testing performed by Edwards showing the presence of all categories of organisms tested for in the Flint River water (Edwards 2015). The top row shows what a negative test result would look like (i.e. bacteria type is not present) and the lower row shows the positive results in all five tests performed on the water during the Flint Water Crisis.



The presence of these bacteria suggests that bacteria associated MIC were in the Flint River water and distribution system during the Flint Water Crisis. This data supports these findings that pitting corrosion was likely irreversibly degrading the copper pipes during this period. The presence of MIC can rapidly accelerate corrosion. Jacobs and Edwards (1998) determined that the presence of sulfides (produced by sulfate reducing bacteria – see 7.1.B) can result in very rapid corrosion of copper pipe. Finding sulfate reducing bacteria suggests this process was occurring in Flint.

7.1.6 Brass Fixtures Corrosion

Brass is one of the most commonly used plumbing materials in fixtures, such as, bath/shower valves, faucets, and angle stops. Brass is an alloy consisting primarily of zinc and copper, but also contains other metals including lead or antimony (which are added to improve machinability). In fact, brass fixtures installed prior to 2014 can contain eight percent or more lead. These brass faucets and valves are a major source of lead inside of households and drinking waters. Based on typical plumbing products installed in the United States, it is likely every household in Flint has some form of brass plumbing components, many of which are high-lead brass.

Corrosion rates in brass depend on water quality parameters. As with copper, phosphates can reduce the corrosion rate due to the formation of a tenacious scale. Of course, the converse is also true: brass passivated by phosphate will corrode quickly if the phosphate addition is stopped, or if the scales are dissolved to expose the brass to corrosive water. The corrosion rate tends to increase with increasing chloride concentrations. Flint experienced a large jump in chloride concentrations as a result of using Flint River water, when compared with DWSD water. Additionally, the use of ferric chloride in water treatment further increased the chloride concentrations. The water source change was made at precisely the same time that phosphate treatment stopped. When exposed to corrosive conditions, the brass is degraded which irreversibly damages the brass, and releases lead into the drinking water.

As an example of the role of the household plumbing components to LCR lead sampling, it was found that the premise piping contributed up to 84 percent of the lead in first draw LCR water samples (USEPA & AWWARF 2008, p. xviii). Essentially, the same highly corrosive conditions that corroded the galvanized service lines (laterals) located outside of the homes also corroded the interior plumbing components of the structure. The affected plumbing components include copper pipes and fittings (with lead solder and leaded brass fittings), brass faucets and valves, brass connectors on plastic piping, and galvanized piping on the inside of the homes.

7.1.7 Lead Particulates

Particulate lead in domestic plumbing is a significant source of lead, impacting both water quality and in the lead content consumed by residents when it exits the tap. Particulate lead has been identified, in the water at user taps in a number of areas in the United States, and can serve as one of the major sources of human exposure to (Triantafyllidou et al. 2007).

There are two plumbing components that are critical to the particulate lead issues: (1) lead service lines which can serve as a source of particulate lead and high-lead content scales; and (2) galvanized service lines that generate both iron and lead particles in the drinking water. If there is galvanized steel pipe downstream of the service lines, lead will build up over time throughout the house, becoming temporarily trapped in the corrosion formations on the steel pipe.

This particulate lead can move through the system, and can be temporarily trapped on the interior surface of the galvanized pipes. This lead can attach to scales or be trapped inside of the textured surface of the corroded galvanized pipes (i.e. tubercles). This accumulation of legacy lead particles can lie dormant, especially if the system is not flushed, until some disturbance occurs (hydraulic or chemical), which can result in the release of high concentrations of lead. Removing the original sources of lead, such as, the lead service laterals, does not immediately address the issue of excessive lead in the drinking water. This condition occurs because the lead has been moved into surfaces of the household plumbing where it can be distributed at a later time. Accordingly, research has shown that lead concentrations can remain elevated for years after lead laterals are removed (Cantor 2006).

7.2 Water Quality Indices Overview

A variety of indexes have been developed to assess the corrosive tendencies of water. These indexes provide water system managers and engineers with critical tools to understand the water quality and what treatment may be required to prevent corrosion. Three of these indexes that are relevant for the issues in Flint are discussed in this section. Changing water quality, particularly due to changes in water source, can have substantial impacts on water quality, and the stability of protective pipe scales in the distribution system.

Corrosion indices are a quick useful tool for determining if a water has corrosive tendencies. These indices are calculated using parameters commonly measured in water systems. These indices include the Langelier Saturation Index, the Larson-Skold Index, and the Chloride-Sulfate Mass Ratio. The engineers involved on this project from LAN and Veolia should have used these tools to quickly and easily determine that the system in Flint was at high risk for corrosion and lead leaching problems. Instead, these tools were basically ignored, and corrosion control was not attempted.

The first of these relevant indexes is the Langelier Saturation Index (LSI) which was developed by Dr. Wilfred F. Langelier of the University of California at Berkeley and was published in 1936. The LSI focuses on calcium carbonate saturation, which results in the formation of a scale (chemically similar to eggshell) commonly found on water pipes. The LSI describes the state of saturation of the solution with respect to calcium carbonate (CaCO3), at equilibrium. LSI ranges are the following:

(1) LSI < 0 : Solution is undersaturated with $CaCO_3$ (*i.e.,* will dissolve $CaCO_3$)

(2) LSI = 0 : Solution is at equilibrium with $CaCO_3$

(3) LSI > 0 : Solution is supersaturated with $CaCO_3$ (*i.e.,* will precipitate $CaCO_3$)

The LSI does not provide a complete picture of the corrosivity of water, but remains a useful tool in assessing water quality with respect to scaling propensity. While a positive LSI does not absolutely protect against corrosion, it is generally advised for water purveyors to provide water that has a stable LSI, i.e. one that is positive (greater than zero).

The LSI is described mathematically by the following equation:

Equation 7.2.A: Langelier Saturation Index (LSI)

$$LSI = pH + log\left(\frac{K_a \times \gamma_{Ca^{2+}} \times [Ca^{2+}] \times \gamma_{HCO_3^-} \times [HCO_3^-]}{\gamma_{H^+} \times K_{sp}}\right)$$

where pH is the negative log of the hydrogen ion concentration, K_a is the acid dissociation constant for bicarbonate, γ is the activity coefficient, K_{sp} is the solubility product of calcium carbonate, and [ ] indicates the molar concentration of the given species. The LSI is impacted by the pH, temperature, and the concentrations of the various species in the equilibrium including calcium and bicarbonate.

The Langelier Saturation Index calculated for December 2014-August 2015 ranged from approximate +0.1 to as low as -1.2. Negative values of the Langelier Saturation Index indicate the water is

undersaturated with respect to calcium carbonate and is generally a higher risk for corrosion/carbonate scale loss. Gnagy calculated a Langelier Saturation Index of -0.12 and -0.17 as shown in his notes in Exhibit 12. This should have been another red flag that should have led Veolia to investigate corrosion issues and clearly and repeatedly document the importance of these issues with City of Flint.

LAN and Veolia should have made use of these simple and widely used equations to evaluate the corrosivity of Flint's finished water supply, but failed to do so. Had they made these calculations, LAN and Veolia would have discovered that the City's water supply was highly corrosive.

The second relevant index is the Larson-Skold Index (LI) which was developed to assess the potential corrosion of cast-iron pipes with water from the Great Lakes. This index dates back to the work of Larson and Skold in late 1950's. The index focuses on corrosivity of water in iron pipes with respect to the influence of chloride, sulfate, and alkalinity in the form of the bicarbonate/carbonate ions. The LI is described mathematically by the following equation:

Equation 7.2.B: Larson-Skold Index (LI)

$$LI = \frac{([Cl^-] + [SO_4^{-2}])}{([HCO_3^-] + [CO_3^{-2}])}$$

where $[Cl^-]$ is the chloride concentration, $[SO_4^{2-}]$ is the sulfate concentration, $[HCO_3^-]$ is the bicarbonate concentration and $[CO_3^{-2}]$ is the carbonate concentration, with all concentrations expressed in milliequivalents per a liter. The LI values are interpreted in the following ranges:

(1) LI < 0.8 : suggest that chloride and sulfate levels are unlikely to cause corrosion

(2) 0.8 < LI < 1.2 : suggests the water is corrosive

(3) LI >1.2 : suggests the water is highly corrosive

The LI provides a useful tool for assessing the water quality, particularly as it pertains to corrosion in steel and cast-iron piping. Generally, water systems should aim to provide water with an LI less than 0.8 to reduce corrosion.

The Larson-Skold Index values, as calculated by Masten 2016 for the period of May 2014- August 2015 showed a range of 1.2-3.8. Any value over 1.2 indicates that the water is *highly corrosive*.

The third relevant index is the chloride-to-sulfate mass ratio (CSMR) which utilizes the chloride and sulfate concentration to assess the corrosivity of water. The CSMR is one of the current best practices for evaluating corrosivity in water systems. Research papers on CSMR have shown that systems with high CSMR values have higher rates of lead leaching (Edwards & Triantafyllidou 2007, USGS 2016). Major water chemistry changes, such as water treatment process changes, and/or source water changes, impact the CSMR and have been shown to impact corrosion in the distribution system (Muylwyk et al. 2014). Regarding CSMR, the Water Research Foundation report concluded that (Nguyen et al. 2010):

The effect of CSMR was confirmed in flowing conditions that are typical in-home systems. Higher CSMR water resulted in higher lead leaching from lead pipe, bronze pipe, and solder galvanically connected to copper.

The CSMR is a simple tool that should have been put to work in the Flint. As discussed above, determining the CSMR is a simple calculation, and the data needed to make that calculation was readily available to both LAN and Veolia and would have enabled any competent engineer to immediately recognize that the Flint water was highly corrosive and posed a serious risk to human health and property in the City. The CSMR was developed by R. Gregory in the 1980's to assess the corrosion impacts of lead in mixed piping systems. CSMR has been used as an assessment of the corrosivity of water, particularly with respect to the stability of lead in brass and lead-copper systems (Edwards, 2007). CSMR can be useful to estimate the impacts on corrosivity due to water chemistry changes, such as was the case in Flint. Research on public water systems has shown that 99 percent of systems with lower CSMR (<0.58) meets the LCR action levels for copper and lead (Edwards 1999). However, water systems that have higher CSMR values (>0.58) only meet the lead and copper action levels 36 percent of the time. In waters with lower alkalinity, research has suggested that CSMR values should be less than 0.2.

The CSMR is described mathematically by the following equation:

Equation 7.2.C: Chloride-to-Sulfate Mass Ratio (CSMR)

$$CSMR = \frac{[Cl^-]}{[SO_4^{-2}]}$$

where $[Cl^-]$ is the concentration of chloride and $[SO_4^{-2}]$ is the concentration of sulfate, both in mg/L. The AWWA Water Research Foundation (WRF) funded research on CSMR as it relates to corrosion and particularly lead issues (Nguyen et al., 2010). That work was published in 2010 and was accompanied by six technical presentations at the American Water Works Association meetings in 2008 and 2009. In that document the authors provide the following guidance regarding CSMR ratios for "lead soldered or partially replaced lead pipe in the distribution system":

(1) CSMR < 0.2: No concern

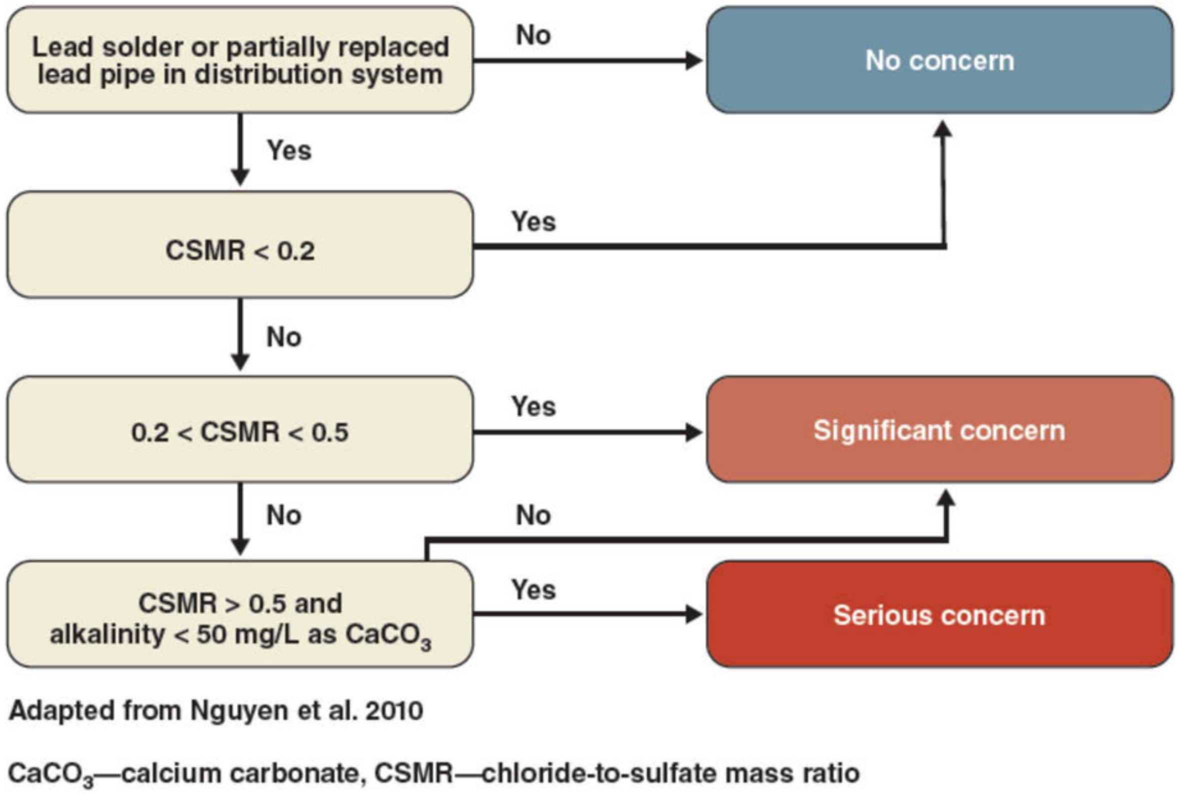
(2) 0.2 < CSMR < 0.5 : Significant Concern (DWSD water)

(3) CSMR > 0.5 & Alkalinity > 50 mg/L $CaCO_3$: Significant Concern (Flint River water)

(4) CSMR > 0.5 & Alkalinity < 50 mg/L $CaCO_3$: Serious Concern

The CSMR in Flint should have been evaluated following the analysis from this figure in Masten, 2016 (adapted from Nguyen 2010). As is discussed in Section 7.3 below, had LAN or Veolia calculated the CSMR for the Flint River water, they would have immediately observed that the water ranged between *significant concern* to *serious concern* for corrosion.

Figure 7.2.A: Decision process tree regarding lead corrosion concerns and CSMR (Masten 2016 / Nguyen 2010). The columns on the right indicate the risks of corrosion based on the water conditions including the presence of lead solder and/or lead pipes, CSMR values and the alkalinity.



As is pointed out by the authors in the 2010 WRF report, most of the potential for lead release in water systems can be evaluated using simple tools and bench scale testing that can be completed in just days to weeks. The water quality indices can be determined in minutes utilizing data that was already collected by the water system.

By evaluating the necessary aspects of the water to allow for the calculations of these indexes, a water system operator/designer/engineer can quickly determine a general view of how the water will behave with respect to corrosivity in the distribution and piping systems. Generally, water with low positive LSI, low LI and/or low CSMR values will be stable and should not cause excessive corrosion in the distribution system. Switching to a water with a negative LSI, high LI, and/or high CSMR is much more likely to result in corrosion, destruction of protective scales, leaching of metals from the distribution and household plumbing systems, and contamination of the drinking water.

7.3 Water Quality Indices in Flint

Corrosion issues are a risk whenever a water system makes substantial changes to the water chemistry. Generally, the operator of a water distribution system strives to keep stable chemistries and make any changes slowly to limit corrosion impacts. In Flint, the water chemistry was changed in a dramatic nature in the span of days, when the City switched to the Flint River water as their sole source. The Flint River had a different starting chemistry compared with the DWSD water, was treated with different chemicals, and was not treated with a phosphate-based corrosion inhibitor. Further, the FWTP had trouble maintaining a stable pH and alkalinity, which further exacerbated the potential for corrosion in the system.

The Flint River is a water source with a history of high levels of corrosivity and much higher chloride concentrations than Lake Huron which is the source for DWSD. Chlorides are a key component in the CSMR corrosion index, providing an obvious indicator that the water from the Flint River would be corrosive to the piping systems in Flint. Chloride levels in the raw Flint River water from April 2014-October 2015 ranged between 38 and 82 mg/L with the monthly average values ranging from 38-54 mg/L (Masten, 2016). Further the FWTP used ferric chlorides to assist with TOC removal, thereby increasing the chloride concentrations in the final treated water. The ferric chloride used as a coagulant further increased the concentrations of the chlorides in the water while the sulfate concentrations remained constant resulting in an increase in the CSMR. It is estimated that the ferric chloride raised the chloride concentrations 28-100% above that of the river water, exacerbating the corrosive nature of the water (Masten, 2016). Veolia recommended further increasing—rather than decreasing—the dose of ferric chloride from an average of 40 mg $FeCl_3$/L to 100 mg $FeCl_3$/L (in terms of chlorides: 26 mg Cl^-/L to 66 mg Cl^-/L) (Veolia, 2015c). It should be noted that this increase is addition to the high and variable level of chlorides present in the raw flint river water. Veolia's recommendation for increased ferric chloride was received by the City's operators, and the City began increasing ferric chloride doses in response to Veolia's recommendation (Glasgow 2020, p.134 L7-24; p.550 L3-p.551 L7).

The results from all three of the corrosion indices discussed above suggested that the water had a propensity for corrosion. These indices continued to suggest corrosive conditions through August 2015, approximately four months after Veolia performed their work and provided their recommendations for the water system. I calculated the Larson-Skold Index and the CSMR were calculated with available data for six dates from May 2014 through August 2015 and is presented in Table 7.3.A.

Table 7.3.A: Calculated values for the CSMR (adapted from Masten, 2016) and the associated corrosion risk based on work presented by AWWA and Nguyen 2010. Sulfate was only measured six times during the operation of the treatment plant and therefore these values can only be calculated six times from 2014-2015. Table adapted from Masten, 2016.

Water Source	Date	CSMR	Alkalinity mg/L as $CaCO_3$	CSMR Corrosion Risk Category
Flint River*	1958	0.35	72	Significant Concern
Flint River	May, 2014	3.4	118	Serious Concern
Flint River	August, 2014	2.8	50	Significant Concern
Flint River	October 2014	2.8	76	Significant Concern
Flint River	February 2015	3.8	47	Serious Concern
Flint River	May 2015	2.9	56	Significant Concern
Flint River	August 2015	3.9	36	Serious Concern
Lake Huron/ DWSD**	2019	0.49	72	Significant Concern

* USGS, 1963 averages ** DWSD 2019 Consumer Confidence Report-averages

As discussed in the previous section, the lower the CSMR values, the lower the concern over corrosion. Values under 0.2 are *no concern* for corrosion and values between 0.2 and 0.5 are a *significant concern* for corrosion, and CSMR over 0.5 are a *significant concern* when the alkalinity is less than 50 mg/L (often the case in Flint). The CSMR in Flint Michigan, while operating on the Flint River water, ranged from *serious concern* to *significant concern*. This information should have been an obvious red flag for the engineers involved in the project that there was a potential corrosion problem.

The CSMR calculation is trivial to perform. It involves dividing the concentration of chloride by the concentration of sulfate. The engineers for LAN and Veolia should have performed this calculation and been immediately aware that the water being served from the Flint River was a very high risk for corrosion and metals leaching in the iron, copper and lead piping systems throughout Flint. LAN performed extensive work on the Flint system and there is no excuse for them not having performed these calculations. These calculations should have been made before the plant was brought into operation and performed again once issues were observed in the distribution system, such as, the broken distribution piping, red water issues, and customer complaints. There is no evidence that LAN ever performed these calculations. There is no evidence that either LAN or Veolia performed these calculations for CSMR.

The data was available for Veolia and LAN to calculate all of the corrosion indices. The calculation of these indices is trivial to perform, and the results would have immediately raised red flags to any engineers with corrosion experience. As discussed further in Section 8.1 and 8.2, unfortunately neither LAN nor Veolia performed the necessary calculations, neither of them addressed the root corrosion issues, and neither of them raised the red flag to bring alert to this issue. These were major and fundamental oversights that needed to be addressed by the engineers on the project. The lack of these efforts led Flint on a course for damaged piping systems and resident exposure to unacceptably high levels of lead.

7.4 Corrosion control technology optimization

Corrosion control strategies and technologies are well understood and established when LAN and Veolia performed their work on the Flint water system from 2013-2015. As an example, DWSD optimized their current corrosion strategy in 1990's which included pH management and orthophosphate conditioning (GLWA 2016). The only proper method to determine the required corrosion control is to perform an onsite corrosion control study. This study would have evaluated the water qualities, such as, pH and alkalinity, with respect to minimizing corrosion, and should have been used to evaluate the requirements and ideal dosing rate for corrosion control chemicals, such as, orthophosphate.

Had the water from the Flint River been treated for optimal corrosion control, including dosing of orthophosphate, many of the problems as they related to corrosion and lead leaching would have been eliminated or dramatically reduced. The optimally treated Flint River water would have remained more corrosive (as evaluated on the corrosivity indexes) than fully treated water from Lake Huron; however, it would have been far less corrosive than the drinking water that was ultimately fed into the distribution system. Such treatment would have avoided many of the issues that occurred due to the lack of proper corrosion control.

The water treatment process that was implemented in at the Flint Water Treatment Plant did not include adequate or modern corrosion control. The process decisions, such as using ferric chloride, further increased the CSMR, increasing the corrosive tendencies of the water.

7.5 The role of engineers in optimizing corrosion control in switching water sources and maintaining water distribution systems

Along with serving safe water that meets regulatory requirements, corrosion control is one of the primary charges of water purveyors. Most water systems spend significant resources to provide effective corrosion control. Corrosion control requires engineering, testing, chemical dosing, optimization, and ongoing monitoring to ensure it is effective. It is now obvious that the City of Flint and its engineering consultants had no effective corrosion control plan in mind during the period when the treatment plant was operated in 2014-2015 (Masten 2016).

The role of a consulting engineer is to provide the sound engineering and technical guidance to the utility. The engineer must be fully familiar with applicable laws and regulations. The engineer must be up to speed and competent in the current state of the art of water treatment and corrosion control. In Flint, LAN and Veolia had the ethical and professional obligation to require that corrosion control studies be performed prior to switching water sources. They further had the obligation to ensure that proper corrosion methods were implemented and optimized before changing water sources.

LAN and Veolia should have provided the City with a road map for the utility to follow to achieve water that would limit and control corrosion in the distribution system. The water quality produced by the utility is essential in maintaining and protecting distribution systems. Failure to perform corrosion control, as was the case in Flint, results in damage to piping systems, both in the distribution system and in the household, and can be result in a variety of issues including exposure to high levels of lead.

Dramatic changes in water quality present significant challenges for corrosion control. The American Water Works Association (AWWA), a trade associations in the water industry, recommends that "…if a municipality is considering changing how its source water is treated, the potential effects on the corrosivity of the treated water and the need for corrosion control should be evaluated" (Muylwyk et al., 2014). The switch from Lake Huron water with corrosion control to Flint River water represented a dramatic change in water quality and water treatment processes. The engineers involved in the switch (i.e. LAN) needed to address corrosion control and perform a corrosion control study as part of their work. No such work was performed. LAN and Veolia similarly needed to perform an analysis of the cause of the corrosion issues plaguing the City once the water source was changed. Had they performed that root cause analysis, they would have quickly identified that the system needed immediate corrosion control.

8 The failure by LAN and Veolia to provide competent engineering services

8.1 LAN's failure to meet the standards of care applicable to professional engineers

LAN failed to meet the standard of care for professional engineers in multiple ways during their work in Flint. LAN was the principal engineer assisting the City with the switch from DWSD to treated Flint River water. LAN failed to recommend or require that the water be treated for corrosion control. LAN failed to assess the possible impacts that corrosive water could have on the distribution piping and the impacts on health of the residents that would occur due to the release of lead caused by the lack of corrosion control treatment. LAN failed to notify to the appropriate authorities and/or the public when they were informed that the MDEQ was not requiring corrosion control, which LAN surely knew was required under the federal regulations and by best engineering judgment. LAN should have provided their client with written documentation of these requirements and notified the appropriate authorities if the City was overruling their recommendations resulting in actions that were harmful to the people and property of Flint. Engineering work performed by LAN directly contributed to, and at a minimum allowed for, the destruction of piping systems throughout Flint, microbial contamination in the distribution system, and exposure of the citizens of Flint to high concentrations of lead.

8.1.1 LAN failed to insist upon a corrosion control optimization study before implementing the switch to the Flint River

LAN failed to require, or even to adequately recommend, that the City of Flint perform a corrosion control treatment plan before switching water sources and treatment systems. A high-quality corrosion control evaluation is needed when switching water sources from a well-treated and corrosion inhibited Lake Huron water to poorly treated and highly corrosive Flint River water. LAN should have insisted that an appropriate corrosion control study be conducted BEFORE the switch occurred. In addition, LAN should have known about the 1998 Snell engineering report, which detailed exactly what was needed to address the issue of the switch to the Flint River water, including the use of a phosphate corrosion inhibitor.

Mr. Green, the lead engineer from LAN on the project, apparently did not understand the requirements or methods involved with modern corrosion control. In his deposition, Mr. Green described his understanding of corrosion control based on softening (Green 2020, p. 30 L12-14):

… however, [Flint was] providing softening. At the time, softening, and today, is an accepted form of corrosion control.

Mr. Greens lack of understanding of modern corrosion control treatment was highlighted by the EPA staff in Mr. Schock's Deposition Vol 1, where he testified as follows [Schock p. 71 (L7-14)]:

When we went to Flint for the first time, we had some conversations with them and with an engineering consultant, they were working with, that was really talking about corrosion control being centered around calcium carbonate precipitation, in kind of old 1930s, 1940s kind of corrosion control.

The person that Mr. Schock met with was Mr. Warren Green, the project lead engineer from LAN for the City of Flint (Schock personal communication 2020). The leader of the LAN team was nearly 100 years behind the times with respect to corrosion control technology, and accordingly the water treatment system implemented did not meet the needs with respect to corrosion control or water quality in the twenty first century. Mr. Green was involved with Flint, since at least the early 2000s, but he had no idea what was involved in conducting a suitable study to address the corrosion evaluation needs before the switch was made.

Mr. Green and his team recommended that the treatment plant be run under a trial run for 60-90 days. However, a meaningful study of this nature to stabilize the corrosion treatment process would take two years, as testified by Mr. Schock of the EPA. That study would have identified the appropriate dose of corrosion control inhibitor (such as, orthophosphate) using pipe loop testing. In the end, there was very limited test trial period conducted before the Flint River water was distributed to the residents of the City of Flint, and that test run wasn't utilized to optimize corrosion control. With regards to the required period for performing a corrosion control analysis, Mr. Shock stated (Schock 2020 p.103 L7-14):

So there's no hard and fast specific time frame, but by and large, in our experience, a couple years is a rough estimate of what it would really take to get a study done. And the studies need to be done, and it's a well-known best practice in the corrosion control field before you make a treatment change that's significantly going to affect corrosion.

Clearly, Mr. Green and the LAN team did not know what was needed to address the corrosion issues involved in Flint. The disastrous results of this ignorance are obvious based on what occurred after the switch to the Flint Water Treatment Plant in 2014 including exposing the residents of the City to high concentrations of lead and irreversibly accelerating corrosion throughout the distribution system and household piping.

8.1.2 LAN failed to identify the absence of corrosion control as a threat to human health and property.

The lack of corrosion control on the Flint River water allowed a highly corrosive water to enter the distribution system. The presence of this water resulted in the release of high concentrations of lead and resulted in irreversible damage to the piping systems throughout houses and business in Flint. As discussed by Dr. Gardoni in his report, "engineers must hold paramount the safety, health, and welfare of the public" (Gardoni 2020, p. 3).

If LAN had identified that the water without corrosion control would result in damage to property and a threat to human health, they had a professional responsibility to report the problem and require that it be addressed as part of their work or work by other consultants. There is no documentation in the written reports from LAN that the absence of corrosion control was a threat to human health and property. Failure to identify these issues and failure to address them accordingly was below the standard of care.

8.1.3 LAN failed to conduct, or recommend that the City of Flint conduct, basic assessments of the corrosivity of Flint River water

The project staff from LAN did not conduct a basic assessment of the corrosivity of the water from the Flint River. We are not aware of any documentation from LAN where calculations or testing were performed to determine if the water from the Flint River was at risk for corrosion issues. Given LAN's years of work in Flint, they should have been aware of the presence of lead pipes in Flint and that a corrosion assessment was absolutely necessary. The staff from LAN should have been aware that the dramatic change in water quality from DWSD (with corrosion control) to the Flint River required a corrosion control study. LAN did not appear to perform any assessment of corrosion concerns, such as, calculating the CSMR values. LAN should have recommended, and in fact should have required, that the City of Flint conduct a corrosion control study prior to the switch. LAN should have performed a root cause analysis of the corrosion issues that occurred once the City was served Flint River water.

The July 2011 report by LAN provides an example of their lack of consideration of the corrosion issues. The report, entitled Analysis of the Flint River as a Permanent Water Supply for the City of Flint, details the adequacy of the Flint River as a source of water and outlines the plant upgrades required. There is no mention of corrosion control in the required plant upgrades and no discussion of the impacts of the highly corrosive Flint River water on the distribution system. This oversight is significant, given the age and the materials of construction of the piping systems in Flint (copper with high lead solder, lead, steel, high lead brass, and cast iron), the use of corrosion control on the lake water previously supplied by DWSD, and the potential impact on the health of the citizens of Flint. It should be noted that LAN recommended lime-soda ash treatment (not supported by the water chemistry). Lime softening does not constitute adequate modern corrosion control, and was never recognized in the water profession as a corrosion control mechanism (in fact the hard scaling water is less corrosive than softened water). Suggestions that lime-soda softening is adequate corrosion control are factually inaccurate and demonstrate an ignorance of water quality and corrosion science.

The report mentioned "phosphate" (type unspecified) in a cost analysis included in the appendix (LAN 2011, Appendix 8, p. 10) but made no recommendation in the text of the report. LAN did not present justification for dosing rates, nor did they include the basis for the inclusion of this word in the appendix. This abstract reference in a cost of service analysis in the appendix of the report is not a meaningful recommendation for corrosion control. Failure to make these recommendations was below the engineering standard of care as they resulted in damage to property and were not protective of human health.

In June of 2013, LAN provided their proposal for the engineering work to put the Flint Water Treatment Plant into service on the Flint River water (LAN 2013). That proposal was negligent in that it did not call for a corrosion control study nor did it specify the installation of corrosion control equipment (LAN 2013). The proposal outlined approximately $2.5MM of engineering consultancy fees for LAN.

The proposal consisted of three tasks: 1) Plant Test Run, 2) Engineering Planning Report, 3) Design Phase Services. No mention of a corrosion control study is made in the proposed scope. The proposed scope provides a description of capital improvements items "a" through "k," totaling tens of millions of dollars (LAN 2011, p. 9). Not one of the line items included either evaluation or installation of corrosion control chemical dosing program. LAN failed to recommend that the City of Flint perform a corrosion control study, and LAN failed to include an assessment of corrosion in the work they performed. LAN

made recommendations to the City on August 22, 2013 regarding the upgrades needed to bring the plant into service. LAN again failed to recommend that corrosion control or a corrosion control optimization study was needed (Green 2020, p. 97 L2-20).

As confirmed by Mr. Green in his deposition, LAN's contract was to assist with the City's needs to upgrade the water treatment plant for fulltime service on the Flint River water as described in the exchange below (Green 2020, Vol. 3, p. 40 L20-p. 41 L4):

[Question] ...LAN committed to evaluating the Flint Water Treatment Plant and upgrading it to provide continuous water supply service for the City of Flint, correct?
...
[Answer, Green] That's what this says.

Mr. Green confirmed that LAN was serving as the "water treatment advisor for the City of Flint" (Green 2020, Vol 3 p. 44 L4-5). In that role, LAN would have overseen the design and engineering for the facility, which necessarily would include water treatment process design and should have included corrosion control evaluations and treatment. Mr. Green later claimed that later LAN's scope was reduced, and they were "no longer serving as a treatment advisor, but were assigned some specific projects to perform" (Green 2020, Vol 1, p. 26 L8-10). However, their contract required any modifications to be made "in writing and signed by the parties or the authorized employee, officer, board, or council representative of the parties…" (Green 2020, Vol 3, p. 35 L9-13). Although there were multiple change order issued on the contract, there is no written record of a change to remove LAN as the *water treatment advisor*. Mr. Green confirmed the lack documentation on the subject in the following exchange (Green 2020, Vol 3, p 54 L22 – p. 55 L3):

[Question] ...So we don't have any written document saying that LAN's scope was reduced, and you don't remember any verbal statement saying that your scope has been reduced, correct?
...
[Answer, Green] No

LAN was contracted to provide critical engineering that the City of Flint required in order to bring the Flint Water Treatment Plant into full-time service. Now years after the start of the Flint Water Crisis, Mr. Green and LAN are claiming that they had a limited role that did not include water quality or corrosion evaluations/treatment. Yet, Mr. Green could not provide documentation that this critical role had been removed from their contract scope.

8.1.4 LAN failed to notify governmental authorities when MDEQ determined that corrosion controls were not required and Flint insisted on only doing what was required by MDEQ

The engineering staff for LAN should have been aware that the Lead and Copper Rule (LCR) and good engineering practice require that a corrosion control study be performed prior to allowing a switch from the DWSD supply to the Flint River. It is the responsibility of engineers in the water treatment field to be familiar with the applicable Federal and State regulations, such as, the LCR, and with good engineering practice. The MDEQ should have required the City of Flint to perform a corrosion control analysis and development of a corrosion control treatment strategy before allowing the switch to Flint River water. LAN should have very strongly encouraged the City to develop a corrosion control strategy, even if the MDEQ did not require one. Unfortunately, Mr. Green and the LAN staff did not insist that a corrosion study be completed before the plant could be placed into operation (Green, 2018; p. 162 L21-163 L2):

[Green]: I felt like that was an issue that needed to be investigated and that we did need to wait until the plant started up to start investigating that.

[Question]: And, uh, what did Mr. Johnson, what was his response to your statement?

[Green]: He told me that he had been told that they weren't gonna do anything that M-D-E-Q didn't require.

Mr. Green provided additional insights on that meeting which included Mr. Daugherty "Duffy" Johnson, the Utilities Director for Flint (Green, 2018; p. 158 L5-11):

[Question]: …what was the nature of your discussion with Mr. Johnson regarding partial softening and corrosion control?

[Green]: Mr. Johnson and I did not discuss partial softening. When Duffy made a statement as the meeting was breaking up to the effect that, well, I guess we dodged a bullet on not having to put in corrosion control, we save the money.

Mr. Green states that he was not comfortable with the lack of a corrosion control analysis prior to start up and expressed that to Mr. Johnson. Mr. Green and LAN had a professional and ethical responsibility to object to the treatment plant start up without a corrosion control study being performed or at least incorporating the installation of a corrosion inhibitor injection system. These actions were below the engineering standard of care, because LAN ignored their duty to inform governmental authorities that their judgement was overruled by the client.

As described in Gardoni's report, the ASCE Code of Ethics states that:

Engineers whose professional judgment is overruled under circumstances where the safety, health and welfare of the public are endangered, or the principles of sustainable development ignored, shall inform their clients or employers of the possible consequences.

Gardoni further expand on this point stating that "…engineers must seek to educate the client and public as to the risks inherent in a decision that the engineer is resisting. The degree of education must be appropriate to the audience and risks" (Gardoni 2020, p. 8). If LAN and Mr. Green believed that the

MDEQ was incorrect, they had a professional obligation to inform their client on the issue (when that decision could harm property and health of the residents of Flint). Those recommendations from LAN to the City of Flint should have been documented in writing.

If Flint elected to override their recommendations regarding the need for corrosion, then LAN had a further obligation to notify the regulators of the error made by MDEQ staff. As highlighted by Gardoni, the "…engineer must alert authorities if the client seeks to implement an action which the engineer believed violates the applicable engineer standard of care and/or results in an unacceptable risk of public harm (Gardoni 2020, p. 8). If LAN believe the decision by Flint and MDEQ would harm the public, those objections must be provided in a written record. Years of work and millions of dollars later, we are not aware of LAN recording any such observations or recommendations.

8.1.5 LAN failed to identify the ongoing corrosion problem or the substantial threats to human health and property that the failed treatment system created even after significant problems emerged

LAN failed to identify that the switch to Flint River water had created significant threats to human health and property as a result of the production of highly corrosive drinking water. LAN continued to work on the project following the plant start-up in April 2014, via a series of contract extensions. By the fall of 2014, the water system experienced a wide variety of problems including: red water complaints, broken distribution pipes, microbial contamination problems, and high levels of disinfection byproducts (TTHMs), and substantial number of consumer complaints.

The treated water was so corrosive that it impacted the General Motors Corporation (GMC) manufacturing processes (Masten, 2016). To address these problems, GMC stopped using the Flint River water via a connection to the Flint Township system (returning to DWSD water) at a cost of over $440,000 to the City of Flint to make the connection.

Even with these issues, LAN failed to raise any red flags about need for corrosion control to the public, to the regulators, or to the City officials. In their *Action Plan* in their report from 2014 on TTHM issues, LAN stresses that "…the City of Flint has signed an agreement with the Karegnondi Water Authority (KWA) to purchase raw water drawn from Lake Huron" and the project is "…expected to be operational by late 2016" (LAN, 2015b). LAN fails to acknowledge any corrosion problems in their reports, and failed to provide a strategy that included corrosion control. Instead LAN (and Veolia) suggested increasing—rather than decreasing-- the ferric chloride dosing which would raise the CSMR, and increase corrosivity of the treated water. LAN concluded the following regarding ferric chloride dosing in the August 2015 (LAN, 2015b, p. 18 of 22):

Increasing the dose rate of ferric chloride is an operation change that can easily be implemented without the need for any additional equipment. Test results show that over 40% [Trihalomethane Formation Potential] removal can be obtained with a dosage of 60 mg/L Fe^{3+} *or higher.*

LAN also recommended that the ferric chloride concentrations be increased in the February 2015 report (LAN 2015a, p. 18 of 22). This recommendation is said to be based on the "2002 Treatability Study [AB&H], jar testing completed by LAN, and a review of 2014 ferric chloride doses compared to THM levels" (LAN 2015a, p 18 of 22).

The corrosion problems occurring throughout the City were ignored by LAN. A simple root cause analysis of these problems would have pointed directly to the lack of corrosion control. Instead, LAN allowed these effects on human health and damage to piping systems to continue.

8.2 Veolia failed to meet the standards of care applicable to professional engineers

Veolia failed to meet the standard of care for professional engineers in multiple ways during their work in Flint. Veolia was the internationally recognized water treatment specialist retained to provide an independent third-party review for the City regarding the issues following the switch from DWSD to treated Flint River water. Veolia failed to identify the presence of highly corrosive water or note the urgency of the need for corrosion control treatment to protect public health and property. Veolia failed to assess the possible impacts that corrosive water could have on the distribution piping and the health of the residents, which would occur due to lead in the City's drinking water caused by the absence of corrosion control treatment.

Veolia failed to inform the City in writing (if they provided the City with such advice at all) that although the MDEQ was not requiring corrosion control, the City was in violation of Federal regulations under the LCR requiring such. Veolia staff was aware of these requirements (Gnagy 2019, p. 280 L. 4-8). Best engineering practices required that the City be informed via written documentation that they were in violation of Federal Regulations and were putting at risk the health of the public and the plumbing systems. Engineering work performed by Veolia directly contributed to, and at a minimum allowed for, the destruction of piping systems throughout Flint, microbial contamination in the distribution system, and exposure of the citizens of Flint to high concentrations of lead.

8.2.1 Veolia failed to identify enormous risks to human health and property posed by the then-current condition of treating and distributing the Flint River water

When Veolia started working in Flint in February 2015, Flint had already received water quality violations from MDEQ regarding the failure to meet the requirements of Total Coliform Rule and the disinfection byproduct standards (for running average TTHMs). As Veolia knew, there were also widespread consumer complaints of red water problems and water main breakage throughout the City. (Veolia 2015a, Slide 5 & 20). The primary Veolia engineers on the Flint project, Mr. Gnagy and Mr. Chen, were aware of many of the issues facing Flint even before their first day on the job as evidenced in Mr. Chen's email following the project kick-off (Gnagy Exhibit 6, p. 2-3). In his own meeting notes, Mr. Gnagy suggests that based on a short review of the water quality data that the water in Flint could be corrosive (Gnagy Exhibit 12, p.8) and states that he suggested to city officials that they may have problems with corrosive water (Gnagy 2019, p. 181 L 23-p. 182 L3) — yet Veolia failed to address these issues in their report or recommendations to the City.

In an email exchange between Veolia's Nicholas and Gnagy dating back to February 9th, 2015, Veolia admitted internally that "Yep. Lead seems to be a problem" (Gnagy 2019, Exhibit 10, p.1) yet Veolia failed to effectively warn the public or the City about potential problems with lead resulting from corrosive water. While Veolia has claimed at times that their work was focused on disinfection byproduct issues, Veolia clearly presented themselves as addressing a much larger scope as discussed above. Veolia ultimately failed to identify the risk that the corrosive water and lack of corrosion control posed to the human health and property.

8.2.2 Veolia did not identify, calculate, or appreciate the significance of the CSMR results that showed that the treated Flint Water was highly corrosive

Veolia received the data required to perform a CSMR calculation from at least two sources (and could have easily obtained the data from Flint if they had requested it), but still failed to perform the calculations (Gnagy 2019, Exhibits 11 & 12). On February 11th, 2015 Gnagy was provided with comprehensive water testing performed at fifteen locations at the University of Michigan Flint which included chloride, sulfate, lead and copper data (Gnagy Exhibit 11). Gnagy claims that the data from University of Michigan-Flint is not representative of the distribution system (Gnagy Volume I, P. 234) which is simply incorrect. These data should have been used to calculate a CSMR. The data collected at University of Michigan-Flint should have indicated to Veolia staff that there were issues with corrosive water that needed to be investigated further. As example of this University of Michigan data and the concerning information it contained, Sample Site #4 (from a drinking fountain) had a lead concentration of 29 µg/L (almost double the Action Level for lead) and a CSMR of 2.4 equating to a *significant concern* for corrosion.

Gnagy was also provided plant data for the raw and treated Flint River water data on February 18th, 2015 (Gnagy Exhibit 12). That data was for December and August 2014 and included chloride and sulfate and the title of the hand written notes was *Corrosion Control Checking 2/18/2015*. Gnagy calculated a Langelier Saturation Index value (LI on the Gnagy notes), but did not calculate a CSMR. The Langelier saturation index values calculated by Gnagy (-0.12 and -0.17) indicate that the water was undersaturated with respect to calcium carbonate, and had a tendency to dissolve calcium carbonate scales. A further investigation into the issue would have indicated the Langelier Saturation Index frequently was lower (ranging as low as -1.2, Masten 2016) indicating even more undersaturated conditions with regards to calcium carbonate. If Gnagy had calculated the CSMR values using the data provided in his notes he would have found a CSMR of 3.3 and 6.3. These CSMR level are characterized as a *significant* or *serious concern* for high corrosivity depending on the alkalinity (Masten 2016, Nguyen 2010) and were an obvious red flag that there was corrosive water being introduced into the drinking water system in Flint. This corrosive water, as indicated by the CSMR was obvious sign that there were concerns for lead release into the water.

In Gnagy's notes from February 18th 2015, he goes on to note that (Gnagy Exhibit 12, Page 8; Glasgow Exhibit 9):

> * corrosive water conditions exist
> discussed w/ plant staff and suggested
> potential issues with lead and copper
> monitoring in the future. Might
> need to balance pH and corrosion
> control with THM compliance issues.

Even though Gnagy didn't calculate the CSMR, he was clearly aware that there were potential corrosion problems in Flint. Veolia had a professional obligation to flag these issues in their presentations and reports. The corrosion problems in Flint damaged property and exposed the residents to lead. Not performing further investigations into corrosion, or even simple calculations to confirm the risks, was below the engineering Standard of Care as Veolia's engineers did not "…hold paramount the safety, health, and welfare of the public" (Gardoni 2020, p. 11).

8.2.3 Veolia failed to recommend that immediately switching back to Detroit water and/or issuing a "do not drink" warning to protect the citizens of Flint given then-current water conditions

Returning to DWSD water would have helped to curb many of the ongoing issues related to corrosion that resulted from the Flint River water. In an email from Veolia's Mr. Chen at the start of the project, he stated that (Chen, 2019, Exhibit 3, p. 1-2):

According to the news… DWSD has just offered to reconnect the DWSD supply line to Flint with no strings attached (no re-connection fee, no long term contract). Many residents are asking to have the DWSD water back (until the new pipeline is ready, including some council members…

It seems that reconnecting to the DWSD for the next two years will be the best solution to satisfy the residents and activists.

Mr. Chen was correct. In his deposition, Mr. Chen discussed his belief at the time of that email that returning to DWSD was "…from a technical point of view, it was the best technical solution" (Chen, 2019, p. 84 L15-16). When asked why he recommended changing back to DWSD, Mr. Chen stated that "the source water is better, the product water will be better. And the citizens demand that. I mean they will only be happy if you reconnect to the city – the DWSD water" (Chen 2019, p. 85 L8-12). Mr. Nasuta, also in the technical department at Veolia stated that (Gnagy 2019, Exhibit 13)

*Talked with Fahey and he made it 'very clear' the technical group needs to point out that the quickest and maybe safest option is to return to Detroit water. We can say that we have not evaluated the cost impacts of that option, if we have not, but we need to tell [Business Development] that this **is an option** and quick to implement.*

I'm not sure what documents, email or your role in any presentation is but please in some form (report paragraph or email best) tell BD that returning to Detroit is an option. If they want to throw that out and not bring it up, that is up to them but we need to be sure to tell them the obvious; there is a quick an [sic] easy fix to this (even if it is not in the scope of work BD asked to look at)"

Returning to DWSD water was the correct and logical option just as it was when the system returned to DWSD water in October 2015. However, Veolia never recommended that the City switch back to DWSD water. Internally, the technical team had the following exchange on the subject of reconnection to DWSD (Fahey, 2019, Exhibit 24):

From: Nasuta, Joseph [joseph.nasuta@veolia.com]
Sent: Friday, February 13, 2015 2:30 PM
To: Marvin Gnagy; Depin (Theping) Chen
Subject: Flint

See the attached comment for Fahey regarding Flint. I think there are some issues at the corp BD level on this but we need to look at it from the technical end only (as we always do). Please keep this between us.

> On the Flint MI project that Marvin is working on. If the best "technical decision is to go back to the City of Detroit as its supplier" we should not be afraid to make that call. Just make sure that the politics of this should not get in the way of making the best recommendation.

jtn

--
Joseph T. Nasuta, PE
Director, Optimization
Municipal & Commercial Business
VEOLIA NORTH AMERICA

Despite the Veolia team's clear internal recognition that switching back to Detroit was the best course of action, the recommendation for a reconnection to DWSD was not included in any of the reports or presentations made by Veolia. Instead of making that technically sound recommendation, Veolia gave in to political pressure and to their own self-interests with regards to additional work with the City of Flint. Mr. Chen notes that on three instances the City informed Veolia that going back to DWSD was not an option. In one such instance, during a meeting with the City Emergency Manager, Mr. Ambrose (Chen, 2019 p. 99 L15-18):

March 18, the public meeting, yeah, I heard Mr. Ambrose said [sic] in person that, you know, they're not going to go back [to DWSD] and it's not an option.

Veolia faced a competing interest. A recommendation to return to DWSD would eliminate their opportunity for potential additional work with Flint (recall that engineers are obligated to put public health above profit by the Pledge of the NSPE). As stated by Mr. Nicholas, a Veolia Vice President in Business Development (BP) in an email to Mr. Fahey (Nicholas 2019, Exhibit 5):

The current intent is to get paid to do a week on site investigation to be clear what is going on, is it fixable and what we would need. That information would be used for defining the scope going forward.

The ultimate focus is not on the water problem but fixing the entire utility. It is a great PPS, Delegated Management or O&M possibility. The water loss is 50% plus and there are problems on the waste water side as well.

The business case was similarly laid out in the pre-project *Go/No-Go* internal evaluation memo (Fahey, Exhibit 7) Veolia ultimately does not present reconnecting to the DWSD system as an option in their presentations or in their reports that were made to the City and the public. In this decision, Veolia violated three of the engineering standard of care requirements as reported by Gardoni, 2020:

- *Engineers "shall hold paramount the safety, health and welfare of the public" (ASCE Code of Ethics, Canon 1)*
- *"Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest" (ASCE Code of Ethics, Canon 4)*
- *Protecting the public from harm must prevail over business and political considerations.*

Connecting to the DWSD system would have resulted in a fast change to a proven, and safe water source which was treated for corrosion control. Veolia failed to disclose their internal conflict of interest and bent to political pressures to provide an engineering option that was not effective in the larger context of the water system. Veolia put their business interests ahead of the needs of the public. In doing so, Veolia contributed to continued degradation of the plumbing systems in Flint, and the continued exposure of the residents to drinking water with elevated concentrations of lead.

8.2.4 Veolia's reports downplayed the corrosion issues as "aesthetic issues" and failed to warn the City and its residents of substantial dangers

Veolia repeatedly downplayed the problems of corrosion through the water system in their presentations and public reports. Veolia was aware that what they told the City staff and officials must also be communicated to the public (Gnagy 2019, p. 65 L6-9) and did a public presentation (Gnagy 2019, p. 65 L 13-15). Downplaying the corrosion issues, as aesthetic issues, was a disservice to the public and was not protective of the public's property nor of their health. Accordingly, this recommendation was not consistent with the accepted engineering standard of care.

In Veolia's February 18th, 2015 presentation to the City of Flint Public Works Committee, Veolia defines safe water as follows (VNA 2015a, p. 3):

- *Safe = compliance with state and federal standards and required testing*
    - *Latest testing shows water is in compliance with drinking water standards*
    - *Monthly reports are available on web page*

The drinking water in Flint was clearly not safe, yet Veolia presents it as such in their presentation, thereby marginalizing the critical risks this water presented to health and the plumbing systems. Veolia hadn't performed tests on the water at this time, and there were red flags related to the water quality including the presence of lead in the University of Michigan-Flint sampling data as discussed above. The water contained high concentrations of THMs, and as a result of the corrosion issues the water was both reddish color and contained high concentrations of lead. The Flint River water was also corroding residents piping systems at an accelerated rate. Regarding the discolored water, Veolia blamed the red water on "old case iron pipes" and stated that there "always has been some discolored water problems – mostly after water breaks" (Veolia 2015a, p. 5) and even claiming that the discoloration has been caused at times by "air built up [sic]" (Veolia 2015a, p. 20). In their final report, Veolia claims that (Veolia, 2015b, p. 11):

- **Discolored Water –** The discolored water is caused by the old unlined cast iron pipe. The water from the plant can have an impact on discolored water, but a greater concern is the breaks and construction work that disrupt the flow of water causing discoloration. A polyphosphate is suggested to help bind the old cast iron pipe reducing instances of discolored water. This along with improve flow of water and programmed hydrant flushing will help, BUT WILL NOT eliminate discolored water occurrences.

Veolia addresses the red water as an aesthetic issue. Their recommendation was to dose polyphosphate to mask the red water issues. Polyphosphate is a chemical that reduces the red appearance of the water, while at the same time increasing corrosion rates. Therefore, the addition of polyphosphates likely would have worsened the situation in Flint with regards to corrosion and lead. Veolia presents the red water issue as something minor, instead of a red flag of the magnitude of the corrosion problems in Flint.

In doing so, Veolia was ignoring the obvious risks of a water system with iron, copper (with high lead copper), and lead pipes without corrosion control. Veolia violated the engineering standard of care by failing to warn the City and its residents of the substantial dangers that the corrosive water presented. The water was in fact not safe, even though Veolia presented it is as such, thereby endangering the public.

8.2.5 Veolia falsely minimized its roles and responsibilities and falsely claimed that lead and corrosion issues were outside the scope of its work.

On Veolia's website (veoliaflintfacts.com), they falsely claim that in Flint they had a limited scope of work and that lead and corrosion issues fell outside of their scope of work. In contrast to those claims, the lead engineer on the project for Veolia said "if we identify an issue that needs to be brought to [the client's] attention, we report it to them" (Gnagy 2019, p. 96 L 20-24).

Yet Veolia never formally documented these concerns or conveyed them to the public or the City. There is no record of Veolia expressing concerns about the corrosion problems or unsafe water to the City or the public.

Veolia was obligated to memorialize their observations and analyses into their reports, yet they didn't do so. Where is the Veolia report that conveyed even the small level of information found in the SEG on operations or the TYJT report on the switch from DWSD to Flint to KWA?

Veolia could have provided an equally competent report. Instead Veolia did not invest the effort and were more worried about their business opportunities than the health and welfare of the Flint residents.

8.2.6 Veolia failed to notify the MDEQ and the City of its belief that is was a mistake to start operations of the FWTP without corrosion controls and that such controls were required by all applicable standards of care.

It must have been patently obvious to the Veolia engineers that during their one week on site to scope things out, that the treatment was incapable of consistent and safe operations, even after ten months of operations (Nicholas 2019, Exhibit 5). The plant was old and did not have an operable central operations center (no useable SCADA). The equipment was unreliable and was marginally functional. The treatment plant did not utilize corrosion control, and the ferric chloride utilized as a coagulant was contributing the corrosion tendencies present in the Flint River water. In fact, Veolia failed to consider changing coagulants, such as to alum, which would have decreased the CSMR and thereby the corrosivity of the water. Lead leaching from plumbing systems has been shown to be sensitive to the coagulant used.

As stated by Professor Edwards (Edwards and Triantafyllidou 2007):

Preliminary data and theory suggest that lead leaching is most sensitive to coagulant type in treating waters with relatively low Cl^- and $SO4^{-2}$, because potential shifts in CSMR are more significant in these situations. Lower alkalinity might also be an important factor, because a low buffering capacity is expected to increase the magnitude of the pH drop at the lead anode.

While the water from the Flint River had chlorides, the result was of the addition of ferric chloride as a coagulant increased the CSMR and contributed to the corrosivity and lead leaching. The soften Flint River water also periodically experienced low alkalinity, which further impacted the lead in the plumbing systems.

In 2015, when Veolia arrived on site, they had to have seen the poor level of operation and maintenance by operators who were lacking in skill and training, including the Chief Plant Operator, Mike Glasgow, who indicated that he had only a few days of hands on operational experience. Mr. Glasgow knew the plant and its operators were not ready to adequately treat the water for distribution. Mr. Glasgow himself indicated that if they started the plant in April of 2014 as the sole source of drinking water for Flint it would be without his support (Glasgow 2020, Exhibit 24). Mr. Glasgow's reservations insecurities regarding premature start up were borne out to be completely true.

The plant performed poorly exhibiting wild spikes in pH, alkalinity, and hardness due to poor quality treatment and a lack of process control. With a high-quality water source, the Flint operators might have gotten away with their errors, but with the Flint River quality, the fate of the operation was predetermined to fail. Veolia had an obligation to report on these problems to the regulators and to city officials.

Veolia operates water treatment plants across the United States. Their technical team was aware that the change in water source should have required a corrosion control study. Gnagy stated as such (Gnagy, 2019, P. 37 L 14-24):

I've already stated DEQ told Flint they did not have to do additional corrosion control treatment. In my opinion that is in violation of the Lead and Copper Rule, because if you make any significant change to source water or treatment, you have to do, under the Lead and Copper Rule, a comprehensive corrosion

control study to implement corrosion control as part of the treatment process. That was not done, and DEQ told them they did not need to do it.

With that knowledge Veolia had an obligation to recommend that a corrosion control study be performed and that immediate actions be taken to address, or at least evaluate, possible problems with corrosion. Instead Veolia downplayed the corrosion issue and made minimal references to corrosion control in their reports and public presentations.

8.2.7 Veolia violated its ethical obligations by placing its economic interests ahead of its obligations to safeguard the public by not disclosing its interest in obtaining a lucrative operating contract and by actively supporting inappropriate decisions by public officials whom it knew were motivated solely by financial concerns but whom were also the decision makers on the operating contract it sought.

This issue is fully presented in the numerous internal memos and emails of the Veolia principals and engineers as has been expound upon previously in this report. In general, this project was driven by the manager of Veolia business development (BD), Mr. Nicholas, who overrode the more technical team, who made it clear that the job that Flint needed was not Veolia's kind of job, and that Veolia was not prepared to present an analysis addressing the significant issues in Flint, such as, those causing the lead exposure in Flint.

Veolia management should have addressed their ethical responsibility to the City and its residents. Instead Mr. Nicholas (who guidance was questioned repeatedly in internal Veolia emails such as, "BD seems to be running the show. Not sure why" [Gnagy 2019 p.263 L 4-5]) was the senior person for Veolia on this project. This unusual approach was undoubtedly driven by Veolia's desire to secure a large-scale operations or management project in Flint. This intent was made clear in numerous internal correspondences including the initial *go-no go* memo analyzing the business opportunity. It is crystal clear that if the City had asked Veolia to take over operations of the water treatment plant (a privatization step that they specialize in), Veolia would have gladly explained what was needed to make the plant reliable and able to produce safe drinking water, before the plant could be used to treat the City's drinking water.

However, instead of either refusing the contract for this project (they were the sole firm who responded to the City's RFP – which was on their minds as to why that was the case [Gnagy 2019 Exhibit 6, p. 1-2]), Veolia moved forward with the hope of future work. Veolia never provided the City with engineering and best engineering judgement (BEJ). Veolia was obligated required both ethically and professionally in order to conduct a conflict of interest free third-party review of the problems in Flint (unless of course the City followed Veolia's intuition to return to the DWSD water source immediately – which Veolia never communicated to the City in writing).

9 Use of the Lead and Copper Rule (LCR) in Flint

9.1 LCR Overview

The Lead and Copper Rule (LCR) is a tool aimed to provide guidance on the effectiveness of corrosion control in water systems over time for skilled water treatment operators and engineers. In one pertinent part, it requires that corrosion controls be adjusted whenever the concentration of lead in the water sample exceeds the Action Level (AL) of 15 micrograms per liter (ppb) for lead in more than 10 percent of the sampled homes. Among other things, the LCR also requires that a corrosion control optimization study be performed, when a significant change in water source was proposed (such as, changing to the Flint River from the DWSD as the City's water source) and that the produced water be generally non-corrosive. Neither LAN nor Veolia ever requested that the City complete this corrosion control study as is required by the law.

The LCR is unique from other regulations on water systems in a number of ways including:

1) The LCR is based on the 90th percentile values for evaluation of the AL standard. Necessarily, 10 percent of the locations tested could have as high or higher lead concentrations than the 15 µg/L AL. As a result, a portion of the residences may be exposed to unlimitedly high concentrations of lead, even when LCR samples show that the system meets the AL threshold. Use of a 90th percentile value has also been manipulated in some water systems to influence LCR values to achieve compliance, either by increasing the total number of samples until the 90th percentile is achieved, by selecting sample locations which are expected to have lower lead concentrations, or by pre-flushing the house before sampling as was reportedly done by the City of Flint.
2) The LCR sampling tends may not account for particulate lead, in the reported results due a combination of sampling methods and analytical processes. Particulate lead has been shown to be a major source of lead in some households.

During the use of the Flint River, it was well documented by the work of Professor Edwards and his students, that many residents were being exposed to unacceptably high concentrations of lead in their drinking water. In fact, Professor Edwards sampling found household lead concentration as high at 13,200 ppb.

9.2 History of the LCR

The US federal Lead and Copper Rule (LCR) was first promulgated on June 7, 1991 and was revised in 2000, 2007 and most recently in 2016. The 2016 revision was triggered in large part due to the Flint Water Crisis. The LCR regulations established a treatment technique rule that includes requirements for corrosion control treatment (CCT), Lead Service Line (LSL) replacement, and public education. The rule requires community water systems to monitor the levels of lead and copper in drinking water at consumers' taps to assess the effectiveness of corrosion control via the trending lead and copper data.

The LCR requires that water quality data is collected at least triennially to determine the ongoing effectiveness of the municipalities CCT. If the lead concentrations exceed the action level (AL) of 15 μg/L or if copper concentrations exceed the action level of 1.3 mg/L in greater than 10 percent of customer taps sampled (i.e., if the 90th percentile exceeds 15 μg/L or 1.3 mg/L, respectively), the system is required to take additional action to control corrosion. Michigan has lowered the lead AL to 12 ug/l which unfortunately will do little to address the issues that have already occurred in Flint.

9.3 Issues with the LCR Sampling in Flint, MI

The method used by governmental authorities in Flint to collected Lead and Copper samples was flawed in a number of respects. Many of these shortcomings are inherent to the LCR sampling methods and have been documented in the literature by a number of respected scientists and academics that specialize in water sampling issues.

For example, research by Professor Edward's group at Virginia Tech has shown that Lead and Copper Rule sampling methods and analysis protocols can sometimes substantially underestimate lead in drinking water, especially if lead is present in particulate form (Clark et al. 2014). Research by the USEPA has also shown that particulate lead is commonly present when lead service laterals (LSL) are present, or when a LSL has recently been replaced (Clark et al. 2014). The extent to which established USEPA protocols can miss or under-report particulate lead concentrations was recently verified, in that for some worst-case over 80 percent of the lead was missed using the standard USEPA sample handling methods (Clark et al. 2014, Triantafyllidou et al 2012, USEPA 2014).

Furthermore, over 99 percent of the lead can be missed in the testing if samples are not thoroughly mixed after acidification (Clark et al. 2014). Additional issues with digestion methods in the assay can cause similar errors causing under measurement of the actual lead concentrations and that these issues are not addressed adequately by the LCR. In a recent set of laboratory experiments, USEPA added particulate lead to deionized water (USEPA 2014) to test how effective the laboratory methods were at accounting for the particulate lead. They determined that particulate lead was not well accounted for by the standard acid digestion process that is typical done for LCR samples (USEPA 2014), thereby suggesting the EPA is aware of the issues with particulate lead.

Lead attached to particulates (*e.g.,* pipe scale, biofilm, particulate stuck in corroded pipe surfaces, etc.) can be released sporadically to a consumer's tap. Often LCR samples are collected by customer volunteers. Defacto the LCR samples are assumed to contain only dissolved lead. However, the testing sampling methods in the LCR should account for the particulate lead as the particulate lead can represents a substantial portion of the lead exposure for water system users.

According to Dr. Marc Edwards, who was among the first scientists to evaluate the cause of the Flint water crisis (Clark et al. 2014):

Traditional lead (Pb) profiling, or collecting sequential liters of water that flow from a consumer tap after a stagnation event, has recently received widespread use in understanding sources of Pb in drinking water and risks to consumer health, but has limitations in quantifying particulate Pb risks. A new profiling protocol was developed in which a series of traditional profiles are collected from the same tap at escalating flow rates. The results revealed marked differences in risks of Pb exposure from one consumer home to another as a function of flow rate, with homes grouped into four risk categories with differing flushing requirements and public education to protect consumers. On average, Pb concentrations detected in water at high flow without stagnation were at least three to four times higher than in first draw samples collected at low flow with stagnation, demonstrating a new "worst case" lead release scenario, contrary to the original regulatory assumption that stagnant, first draw samples contain the highest lead concentrations. Testing also revealed that in some cases water samples with visible particulates had much higher Pb than samples without visible particulates, and tests of different sample handling protocols confirmed that some EPA-allowed methods would not quantify as much as 99.9% of the Pb actually present (avg. 27% of Pb not quantified).

In summary, the methods utilized to collect and measure lead concentrations for LCR sampling in Flint under reported the lead concentrations at levels below the lead levels consumed by the residents of Flint. The LCR sampling data may have been affected by a combination of sample location selection, sampling and analytical methods, pre-flushing, and the inability to quantify the particulate lead that was present. As has been documented in the literature, such as, the work by Drs. Masten and Edwards, the residents of Flint were exposed to levels of lead that exceeded the AL. The LCR sampling shortcomings meant that these impacts were not reflected and the results provided gave a false sense of security based on misleading and incorrect representations of the actual lead concentrations in the drinking water.

10 The Citywide Impact of the Engineering Failures by LAN and Veolia

10.1 Overview

It is well known that for 19 months, beginning in April of 2014, Flint's drinking water was comprised of chloride laden water from the Flint River that was not treated to minimize the corrosion potential. Corrosion control was not implemented or investigated prior to the switch over to Flint River water. This remained true during the entire period that the Flint Water Treatment Plant was in service, even though the Federal Lead and Copper Rule (LCR), and reasonable engineering standards, required a study, treatment to reduce corrosion, and the production of generally non-corrosive water. The highly corrosive water produced from the Flint River treatment plant was distributed throughout the City and impacted all piping systems, appurtenances, and residents.

The corrosive water that was distributed throughout Flint damaged piping systems and resulted in the release of lead from a variety of those plumbing components. Sources of lead included internal pipe scales, lead lateral pipes, leaded brass, leaded solder, and galvanized pipes. The harm caused by this 19-month period is still being observed today and requires a comprehensive remediation approach to address these problems and to restore the confidence of the public in the water system.

One of the internationally recognized organizations on water treatment, the Water Research Center, identifies eight groups of factors that accelerate corrosion, pitting corrosion in particular, including low pH or high pH, high dissolved solids, high chloride to sulfate ratio, corrosion related bacteria(especially sulfate reducing bacteria), high suspended solids, high corrosion byproducts in suspension, high temperature, and high flowrates. Many of these agents or conditions were present in the Flint River water and distribution system. Even a casual inspection of the situation would have shown that the new Flint River water would be far more corrosive than the DWSD water.

Edwards (2016) discusses how these conditions while on Flint River water affected corrosion rates in the system. Iron corrosion was as much as 8.6 times the corrosion rate with Flint River water when compared with DWSD water; lead-soldered copper pipes gave off 19 times the amount of lead with the Flint River water over DWSD water.

In April of 2014, Flint's water distribution system was changed over from imported water bought from Detroit (DWSD water sourced from the Detroit River and Lake Huron) to local water from the Flint River. The Flint River source was much higher in chloride than the DWSD water, a difference magnified by the City's use of ferric chloride in the treatment process. Another critical difference in the source waters was that the Flint River had much higher concentrations of dissolved organic matter.

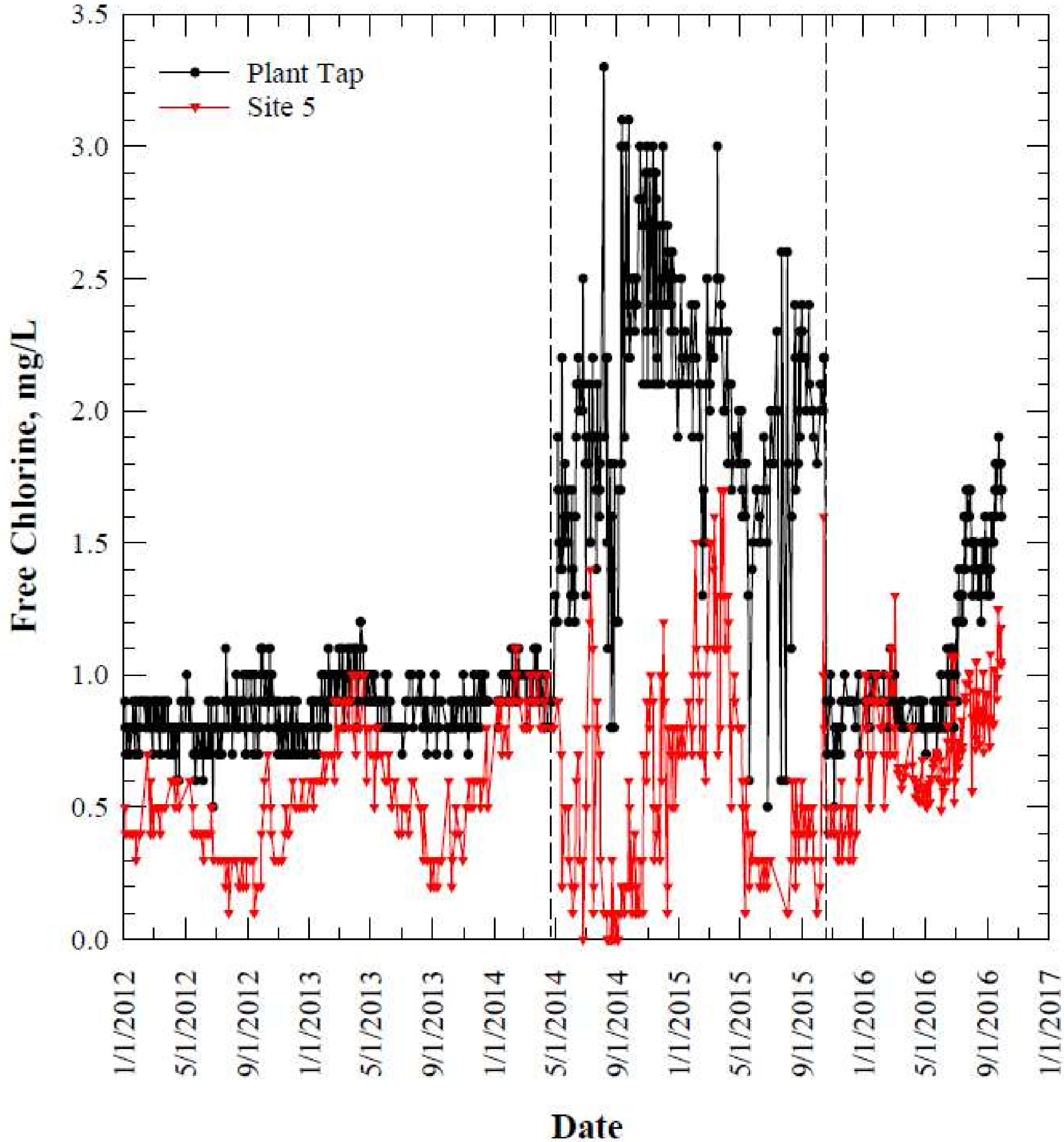
Comparing the treated water from Detroit, the Flint system typically had at least three times higher chloride concentrations, and three times or more CSMR values. During the Flint Water Crisis, critical water quality parameters with respect to corrosion control, such as, the pH and alkalinity, were unstable and were frequently low due to poor process control (Masten 2016); calcium and magnesium also had a larger range due to poor process control. During the Flint Water Crisis, the system also failed to maintain a stable consistent disinfectant residual throughout the distribution system. As a result, the chlorine residual was at times quite low, and in some cases even not-detectable (i.e. no disinfectant was present) (Masten 2016). Finally, the water imported from the DSWD had been treated with orthophosphate for corrosion control. No orthophosphate was added to the treated Flint River water. No corrosion control

study was performed to determine optimum chemical dosing and water quality parameters to limit corrosion.

The Flint piping system had developed internal pipe scales as a result of Detroit's use of orthophosphate for corrosion control treatment. These pipe scales began to dissolve and release once the highly corrosive Flint River water was introduced. The phosphate scales helped provide a protective coating on the interior of the pipes. These scales were destabilized which made the pipes subject to increased corrosion. The scale destabilization was the result of the wild changes in treated water quality, and the lack of an orthophosphate addition. Further, those pipe scales can contain high concentrations of metals including lead. The scales had been immobilizing the lead and other metals, but began to release the lead once the water source water was changed to the Flint River.

After the changeover, the Flint distribution system was frequently subjected to highly variable, and at times very low/not-detectable levels of residual disinfectant (chlorine). Residual disinfectants help control the formation of biological films inside of the distribution system. These slimes promote enhanced corrosion via Microbially Induced Corrosion (MIC). The figure below shows the chlorine residuals at the sample tap located in the treatment plant (*Plant Tap*) and at a location in the distribution system (*Site 5)*. As can be seen at *Site 5*, the chlorine concentration was consistently low, and at times dropped to 0.1 mg/L or as low as 0.0 mg/L of free chlorine (the disinfectant used in Flint). The EPA requires a disinfectant residual of a minimum of 0.2 mg/L.

Figure 10.1.A: Summary of free chlorine residuals at test sites in the Flint distribution system January 2012- September 2016. The left axis shows the free chlorine residuals in mg/L. The black line shows the free chlorine concentrations leaving the treatment plant and the red line shows the concentration from one of the distribution monitoring stations "Site 5." The vertical dashed lines show the period of operation on the Flint River water from approximately May 2014-October 2015. The distribution system concentration (red line) were highly variable at "Site 5" and were frequently at or below 0.2 mg/L. The Flint system, when operating on the Flint River water, was out of control and did not consistently provide water with the required residual disinfection levels or that was safe to drink. (Figure source: USEPA 2016).



As can be seen in Figure 10.1.A there were two periods with consistently low levels of residual disinfectant, one in the summer of 2014, the other in the summer of 2015. These periods were likely associated with excessive biological growth in the piping systems given the high concentrations of biologically available organic matter in the treated water and low/non-existent chlorine concentrations.

The Flint River is a water source with high total organic carbon (TOC) which presented treatment challenges for the Flint Water Treatment Plant. The treatment methods used to treat the Flint River water, such as ozone, resulted in the formation of high levels of assimilable organic carbon (AOC). AOC can provide a ready food source for biological growth in the distribution system. Coupling the high levels of AOC with low levels of disinfectants was a perfect recipe for biological growth and enhanced MIC. Factors contributing to chlorine demand in the distribution system included extended water age, an aging cast iron piping system, and excessive biofilm growth.

The presence of biofilms was likely one of the factors that contributed to enhanced corrosion during the Flint Water Crisis. Further, the conditions that promoted biological growth in the system likely allowed for, and contributed to, the series of Legionnaires' Disease outbreaks which occurred in Flint during this period. Legionnaires' Disease is a form of pneumonia caused by pathogenic bacteria known as *Legionella* and can be deadly to those who contract the disease. *Legionella* has historically been found in systems lacking adequate disinfection. The Legionnaires' Disease outbreaks that occurred during the Flint Water Crisis have been shown to be correlated with the occurrence of inadequate levels of disinfectant in the distribution system in Flint (Zahran et al. 2018).

Leaded solder was banned in 1986 (effective June 1988). The majority of the homes in Flint were constructed prior to 1986, and therefor contain high-lead content brass, and if plumbed with copper pipes, the pipes were joined with high-lead content solder. High lead brass fixtures were allowed in the United States until a federal law prohibited them in 2011 (effective 2014). Based on a review of the 2016 parcel records in Flint, 99.2 percent of the houses were constructed prior to 1988, and greater than 99.99 percent of the homes were constructed prior to 2014 (FlintGIS parcel records, 2016). Therefore, almost all homes plumbed in copper in Flint used high-lead solder. Further, almost the all homes in Flint have brass plumbing fixtures that were installed before 2014 which contained high concentrations of lead. The high-lead solder and fixtures released lead into the drinking water during the period when the water system was supplied with corrosive Flint River water.

As was noted by Professor Masten (2019), these fixtures are a source of lead and their removal may be an effective method for reducing human lead exposure. The brass fixtures are directly connected to steel pipe in many homes in Flint which contributed directly to deterioration of the piping systems while exposed to the Flint River Water and this causes galvanic corrosion which further reduced the life of the piping system.

This type of metallic deterioration occurs when two dissimilar metals are in contact and is known as galvanic corrosion. Galvanic corrosion occurs in the same manner as a battery works to produce electricity. The anode (the battery casing) in a dry cell battery is destructively corroded to produce an electrical current. In the same manner, the anodic metal in the water system—the piping inside the homes--corrodes to produce a current flow that is accompanied by the release of metal ions into the drinking water. When a steel pipe and brass plumbing fixture are directly connected in a plumbing system, the steel pipe will corrode to release metal ions (including the lead containing scales) and electrons into the water. Similarly, high-lead solder will corrode when connected directly to copper (sweated fitting) to

release lead ions, when the water conditions support corrosion. The water served from the Flint River without corrosion control presented exactly the type of conditions that cause (support) corrosion and consequently the deterioration of piping systems and the release of lead.

10.2 Impacted Plumbing Systems and Residents

During the evaluation of Flint, it was discovered that four types of structures were impacted by the corrosive water from the Flint River with regards to lead, namely:

1. Homes and businesses that evidenced elevated lead levels in the drinking water. These locations likely contain significant sources of lead deposited in their piping systems, and will require the installation of a new piping system to rectify this problem.
2. Homes with lead laterals having interior plumbing, or fixtures, where lead was dissolved and/or deposited. Thus, lead would have leached into the drinking water after being dissolved or abraded by the highly corrosive Flint River water. These structures will require the installation of new piping systems and *no-lead* fixtures throughout.
3. Homes built before 1988 that were constructed with high lead solder, and those that were constructed before 2014 with high lead brass valves and faucets. By far, the majority of homes (99.2%) in Flint were built before 1988 and essentially all (99.99+ %) were built before 2014 (EPA banned high lead solder effective June 1988) (FlintGIS parcel records 2016). The only solution to reduce the resident's exposure to lead in their drinking water from these sources is full replacement of these soldered connections, valves, and fixtures with new components. The replacements components should meet the *no-lead* standard of less than 0.25 percent lead and be in compliance with NSF 61/NSF 372.
4. All structures with plumbing materials that have lead scales in the pipes resulting from the reaction of the lead with the phosphate water additive. The internal surfaces of the residential plumbing pipes are now loaded with lead corrosion particles. The high lead containing corrosion products have been incorporated into the scale on the pipe interior surfaces. This lead contaminated scale can be released whenever either hydraulic (abrasion) or chemical conditions are adverse for the scale.

Five plumbing materials types have been identified as being damaged by the corrosive water from the Flint River. The plumbing material types are lead, steel, copper, brass, and plastic. All of these material types were negatively impacted by the highly corrosive treated Flint River water. All of the metallic material types suffered from damage due to aggressive corrosion, resulting in reduced wall thickness or pitting corrosion. The use of plastic piping for domestic plumbing is a relatively recent development and only utilized in a relatively small portion of the homes in Flint (likely during remodeling). The first Flint home that reported high lead levels was plumbed with plastic pipe (Pieper et al. 2017). All of the five material types have been impacted by the formation of a dissolvable lead scale on the surface.

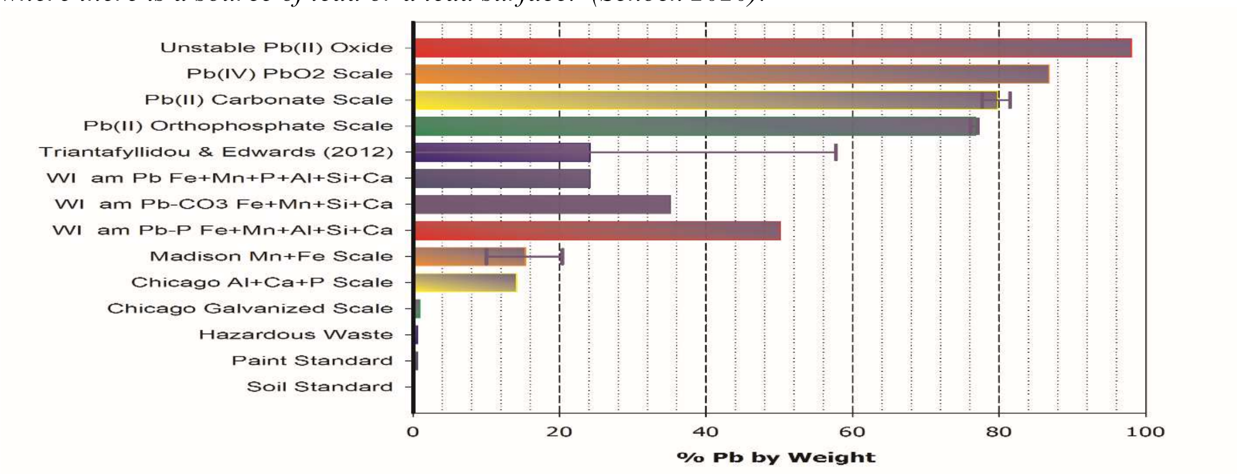
The interior of these houses plumbing systems are now contaminated with scale containing lead. That lead containing scale can continue to contaminate the drinking water for the foreseeable future. These contaminated pipes require replacement to positively correct this situation.

The lead scale formed from the lead utilized in the plumbing system. Locations containing lead include: lead lateral pipes, lead pigtails (cast iron pipe joints), leaded solder, and leaded brass. The dissolved lead reacted with the phosphate, added to the DWSD water for corrosion control which formed an insoluble coating on the inside of the pipes, which could easily contain over 50 percent lead. When switched to the highly corrosive Flint River water in 2014, the scale began to dissolve and flake off resulting in high

concentrations of lead at consumers taps. Leaded scales began to reform after the return to DWSD water in 2015, which was treated with elevated levels of phosphates.

As shown by Roy, Tang and Edwards 2019, immediately after the switch over from the DWSD water, the scale began to deteriorate. This process was documented in the elevated lead levels that were observed at the wastewater treatment plant. Similarly, Michael Schock from the EPA testified that the protective phosphate-based scale, deposited over years of using the DWSD water, would have begun to dissolve within days of the switch over to the Flint River water. This high lead scale was ingested by the resident of Flint. As shown in Figure 10.2.A below, these lead scales can consist of upwards of 50 percent lead by weight. The released scales were ingested by the residents of Flint in their drinking water and represented one of the exposure pathways for the Flint residents during the Flint Water Crisis.

Figure 10.2.A: This figure summarizes the lead content of the scales that form on the inside of pipes where there is a source of lead or a lead surface. (Schock 2020).



The damage that occurred to the plumbing systems is irreversible. The damage to public health resulting from lead exposure is irreversible. The damage occurred due to the absence of corrosion control and the wild swings in water quality that resulted from poor design and process control at the Flint River water treatment plant (Masten 2016). These problems could have been avoided, or at a minimum dramatically reduced, had the engineers from LAN and Veolia met the standard of care requirements for their work in Flint.

The corrosive water in Flint was distributed to all locations throughout the City between April of 2014 and October 2015. This highly corrosive Flint River water was distributed to all residents in Flint, as there is only one distribution system with a sole source of water. Water that enters the City's system exits it through the residential taps (Zhang 2019, Adeosun 2014, USEPA 2002a, USEPA 2002b). Therefore, it can be said with confidence that ALL homes in the City of Flint were exposed to the same highly corrosive water, as there was a sole source of water in the City of Flint.

We have developed two methods to further explain this fact that all houses in Flint were exposed to the same corrosive Flint River water:

The first method is based on physics, or more specifically conservation of mass. The principal of the conservation of mass states that for any closed system, the mass must remain constant. In lay terms, for a distribution system, water comes in from the source, and leaves through outlets including household fixtures, fire hydrants, or broken/leaking pipes. The Flint distribution system had only one source, the

treated, but highly corrosive, water from the Flint River treatment plant. The treated water enters the distribution system and is distributed throughout the community. There are no other sources that feed that system. Accordingly, all water originated at the Flint Water Treatment Plant. That same water flows through the mains, the service laterals, and out through the household taps.

The second method is based on the measured chemistry of the water. This type of analysis relies on something known in the field of environmental engineering as a conservative tracer. Conservative tracers are chemical constituents of the water, that are not increased or decreased in concentration within the system. This behavior results because they do not react within the system, and there are no additional sources or sinks within the system being modeled. In the context of Flint, this indicates that the tracer would have the same concentration throughout the distribution system (and in the houses), as it had when it left the treatment plant.

Chloride (or sodium) is a perfect tracer, as it fully dissolves into the water and it has very few complexing or precipitation reactions. Once the chloride is dissolved in the Flint drinking water it will stay in solution throughout the entire distribution system. The chloride level leaving the treatment plant remains constant throughout the distribution system. Similarly, the CSMR and the corrosivity, can remain constant or increase in the distribution system. Any decreases in sulfate concentrations within the system would result in an increase in the CSMR and the water's corrosivity.

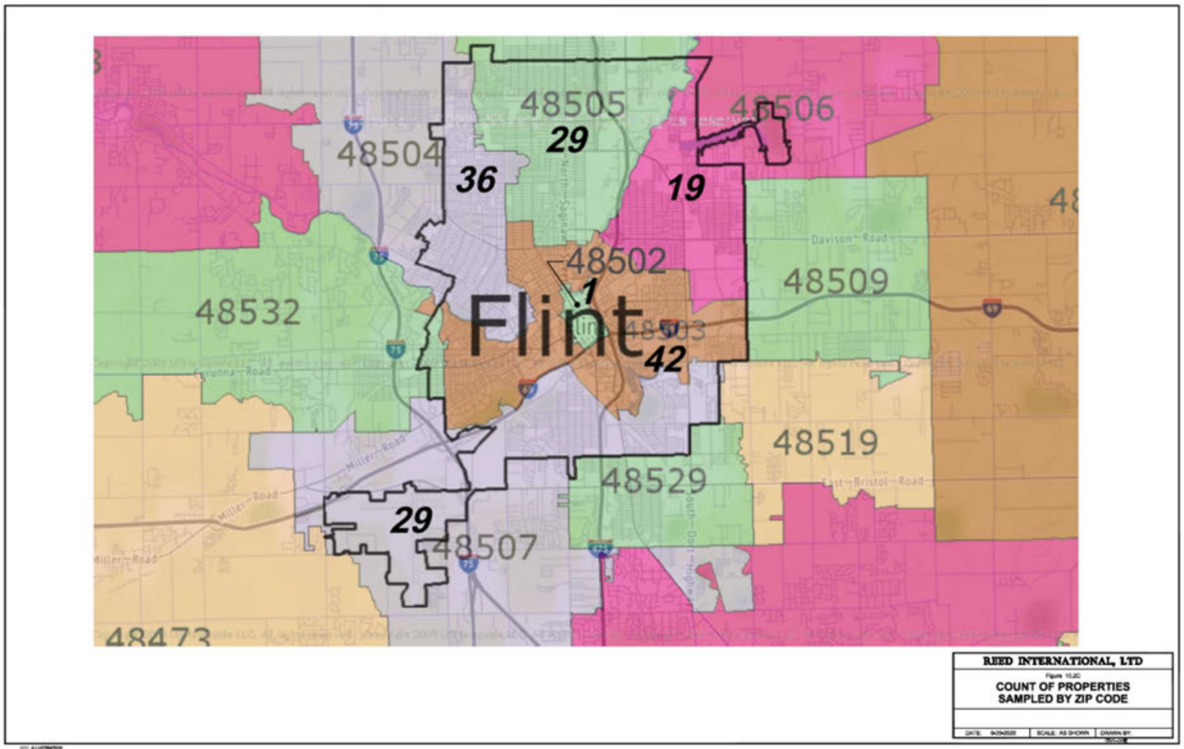
With regards to corrosivity and CSMR, within the distribution system the corrosivity can only behave in one of two ways:

1) Remain constant at the values leaving the treatment plant (corrosive water)
2) Increase CSMR from the values leaving the treatment plant (even more corrosive water)

This potential increase can occur because the protective sulfate concentration may decrease within the distribution system due to microbial reduction by sulfate reducing bacteria.

Measured chemistry analysis was utilized as a proof that all houses in Flint were exposed to the same water. The raw water quality data collected from 156 Flint households distributed around the City was used in this analysis (unpublished data collected during sampling described in Pieper et al. 2018). Two example compounds of conservative tracers in the water system are sodium and chloride (the ions that make up road salt). The dataset analyzed included four sampling events, one in August 2015 when City residents were consuming Flint River water, and three following the return to DWSD water. The location of the 156 houses are shown by their Zip Code in Figure 10.2.B. As can be seen in the figure, the properties sampled were distributed through the City of Flint.

*Figure 10.2.B Map showing the zip codes in Flint. The **bold** numbers indicate the quantity of the 156 houses that were sampled in Flint in each zip code (unpublished data Pieper et al 2018).*



To analyze the dataset, we performed two types of calculations. The first involves calculating the *mean*, which in lay terms is known as the average. The second involves calculating the standard deviation. Standard deviation is a statistical tool to evaluate the spread of the dataset. The smaller the standard deviation, the less variability, or spread, of the data.

In a real-world system, such as Flint, there is necessarily some variation in a given dataset even for a conservative tracer (like chloride) due in large part to lab and sampling inconsistencies or variations in the source water (Flint River). The standard deviation is expressed as percentage in the table below. None the less, the parameters analyzed, across four different sampling dates, support that all residences in Flint were exposed to the same concentration of chlorides in their drinking water. This finding is indicated by the relatively small variation (standard deviation relative to mean values) spread across all 156 houses sampled.

Table 10.2.A: Analysis of two water quality tracers measured at 156 houses in four sampling events (August 2015, March 2016, July 2016, and November 2016). Mean and standard deviation (expressed as a percentage of the mean) were calculated for each parameter. Data adapted from unpublished Pieper et al. 2018 data.

Date	**Sodium ppm [Mean +/- standard deviation %]**	**Chloride ppm [Mean +/- standard deviation %]**
August 2015 Flint River	**20.6** +/- 5%	**83.6** +/- 3%
March 2016 DWSD	**44.3** +/-7 %	**36.3** +/- 10%
July 2016 DWSD	**52.7** +/- 6%	**11.2** +/- 4%
November 2016 DWSD	**50.1** +/-8%	**10.8** +/- 11%

Table 10.2.B. below shows two critical parameters for corrosion that were documented during the testing: phosphate and CSMR. The DWSD water was treated for corrosion control, including the use of orthophosphate. The Flint River water had higher CSMR values, indicating high risks for corrosion in the system, and no orthophosphate treatment.

Table 10.2.B: Analysis of CSMR and phosphate concentrations in the water sampled at 156 houses in Flint, 2015-2016. Values for chloride, sulfate and phosphates are mean values across the dataset. Data adapted from unpublished Pieper et al. 2018.

Date	Phosphate ppm	Chloride ppm	Sulfate ppm	CSMR	CSMR Corrosion Risks
August 2015 Flint River	0.1	83.6	96.6	0.86	Serious Concern
March 2016 DWSD	3.4	36.3	80.6	0.45	Significant Concern
July 2016 DWSD	3.0	11.2	74.8	0.15	No Concern
November 2016 DWSD	3.2	10.8	81.4	0.13	No Concern

ALL houses in Flint were exposed to the highly corrosive Flint River water, uniformly during the Flint Water Crisis. As shown in the data analysis above, the water chemistry was consistent across the City. During the Flint Water Crisis, all homes were exposed to the highly corrosive water with similar CSMR values. Accordingly, all homes received less corrosive water once the water once returned to the DWSD system.

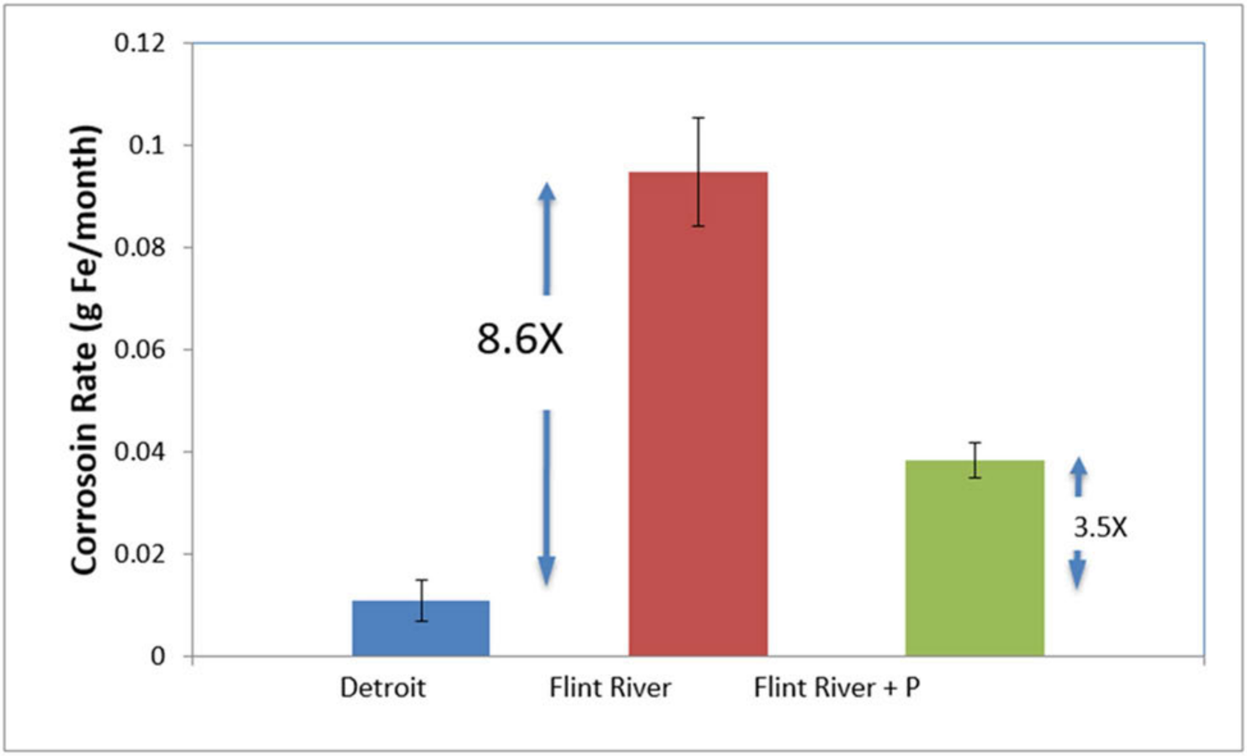
10.3 Steel Piping Materials

The life of Flint's plumbing systems has suffered from rapid aging caused by the highly corrosive water distributed to the City of Flint in 2014-2015. The life of the steel premise plumbing has been cut short. This corrosion rate is estimated to have been up to 8.6 times faster than what was experienced on the DWSD water, based on the work of Dr. Marc Edwards. This reduction in pipe life means that a steel pipe installed in a house in Flint that would have lasted 30 years on the DWSD water would only last 3 years with exposure to the treated Flint River water (http://flintwaterstudy.org/2015/09/research-update-corrosivity-of-flint-water-to-iron-pipes-in-the-city-a-costly-problem/).

A piece of bare steel dipped into water with the chloride concentrations in Flint's water distribution system would start rusting immediately (as can be seen in the photo of two steel coupons tested by Virginia Tech University below in Figures 10.3.A & 10.3.B).

Figure 10.3.A: Steel corrosion coupon testing on DWSD water (top) and treated Flint River water (bottom). Note that extensive rust formation (corrosion) on the coupon exposed to the Flint River water. Both specimens were exposed for the same amount of time, demonstrating the substantially higher corrosion rates resulting from exposure to the treated Flint River water (Flintriverstudy.org; Edwards, 2015).

Figure 10.3.B: Corrosion rate testing on DWSD water vs the treated Flint River water. DWSD water is shown on the left in blue, and the Flint River water is shown in the middle column in red. Note that the corrosion progressed almost nine times faster in the Flint River water. The green column on the right shows the same test performed with treated Flint River water with orthophosphate added. Note the reduction in corrosion rate that could have been achieved ([Flintriverstudy.org], Edwards et al. 2015).



Once the pipes start rusting, they stay rusted. The wall thickness that is lost in the corrosion process is gone forever. Additionally, the internal surfaces of the residential plumbing pipes were loaded with lead phosphate scales built up the years the system operation on DWSD water. Release of these high lead scales was caused by the switch over to the highly corrosive Flint River water in April 2014.

The surface of the steel pipes are now loaded with lead corrosion products from the lead sources present in the water system, such as, lead service laterals and high lead brass water meters. The pipe interior surfaces have a significant amount of lead containing corrosion products that have become incorporated into the scale on the interior of the pipe since the Flint water source was returned to DWSD. This contaminated scale can be released whenever either hydraulic or chemical conditions are adverse for the scale. It is not sufficient to only remove the lead service lateral to address the lead problems in Flint. The issue includes the steel pipes which now contain particulate lead and lead trapped in the new scales formed since the return to DWSD water containing orthophosphate.

Steel water piping is problematic even when there are no lead service laterals present. When the steel pipes are combined with lead service laterals, the stage is set for disaster. As the lead scales began to deteriorate in the Spring of 2014, the lead particles were released into the drinking water. The surface of steel water pipe is very rough due to the formation of corrosion tubercles on the pipe's interior. The tubercles increase the surface area for lead to adsorb and for the heavy lead particles to become trapped. These conditions ultimately allowed for more lead to be released during events like the Flint Water Crisis.

As a result, when water flows are increased during typical use, these trapped particles can be re-suspended and flow into the residents' tap water. This process continues to occur even years after the water is returned to DWSD. Roy, Tang, and Edwards (2019) have shown that the leaded particles were being (and continue to be) discharged routinely through the residents of Flint and into the City sewers. The lead is then incorporated into the City's sewage sludge where it can be quantified. Said another way, the amount of lead that continues to be released into the Flint residents' homes is enough to be detected at elevated levels at the wastewater treatment plant servicing Flint.

The only way to stop this problem from occurring, thereby eliminating the exposure of the residents to lead trapped in the steel pipes, is to bypass and/or replace both the leaded lateral and the contaminated steel pipes.

Although the protective piping scales was disrupted during the Flint Water Crisis, the scale has since had time to be reestablished due to the high phosphate doses that are currently being supplied. The lead service laterals remained in place until recently due to lateral replacement program. Unfortunately, this scale has trapped lead particles that were present on the interior of the steel piping and will become re-dissolved/resuspended in the drinking water at any given time when the conditions are adverse to scale preservation. These scales represent an ongoing risk for lead exposure to the residents of Flint. Especially those with steel piping systems that have lead phosphate scales in place.

Washington DC has a long history of problems with lead in their water system in a manner similar to the problems of Flint. As noted by, the DC Water and Sewer Authority and as is stated on their website, regarding the fate of corroding galvanized pipes (https://www.dcwater.com/faq-page/15#t15n901):

> WHAT DO I DO IF MY HOME HAS GALVANIZED PIPES?
>
> The only way to fully ensure that lead is not mobilized from galvanized plumbing in a home is to fully replace the galvanized plumbing.

10.4 Lead Solder Joining Materials

It has been demonstrated that high-lead solder, common throughout Flint, corroded at a rate of 19 times faster when exposed to the Flint River water as compared with the DWSD water (http://flintwaterstudy.org/2015/09/test-update-flint-river-water-19x-more-corrosive-than-detroit-water-for-lead-solder-now-what/). This accelerated corrosion rate for high-lead solders resulted in even more exposure for the consumers to the lead in their drinking water.

A large proportion of the homes in Flint were built between 1897 and 1942, and were serviced with lead laterals and/or plumbing components joined with high lead solders. The town is populated with old houses that were full of lead containing fixtures and served by lead service laterals. Due to the economic conditions in in Flint, most of the homes had not been remodeled and therefore still contain the high lead fixtures and solder.

The homes with copper piping, and consequently leaded solder, were exposed to increased levels of lead that was released from the solder during the Flint Water Crisis. The joining of copper pipe with high lead solders creates a dissimilar metals connection. Dissimilar metals cause corrosion of the less noble of the metals (lower electrochemical potential). Based on the work of Edwards cited above, the high lead solder is less noble than copper, and the solder will attempt to protect the copper pipe that is immediately adjacent by corroding and dissolving lead into the drinking water.

The corrosion in leaded solder joints tends to occur in the capillary space between the copper pipe pieces (where the solder is exposed). That area is attacked and begins to dissolve into the drinking water. Due to location where this type of corrosion occurs, it is unlikely that this type of corrosion would cause an external pipe leak. None the less, the leaded solder exposed the residents to higher levels of lead. Unfortunately, the only way to remove this problem of the high lead solder corrosion is to bypass the plumbing in the house, replacing it with plastic pipe or new copper pipe that is joined with modern NSF 61/NSF 372 compliant solder.

CSMRs exceeding 1 have been shown to dramatically increase the rate of high lead solder corrosion (Nguyen et al. 2011). Recall that the Flint River water had a CSMR of 3.8 during the Flint Water Crisis. Operation on Flint River water in 2014-2015 released lead into the resident's water and caused corrosion of the leaded solder joints.

10.5 Copper Piping Materials

Structures plumbed with copper piping have also suffered. Copper was also subject to attack of the corrosive Flint River water. There are two types of corrosion; namely, uniform and non-uniform. To aid in understanding the difference between these types of corrosion, there is a logical analogy to car tires. Uniform corrosion results from an attack on all metals surfaces in a similar manner to the way a car tire wears out. The tire starts out its life with full tread depth and then over time it simply disappears. In the case of plumbing metals – the metal also disappears (dissolves) into the water and ultimately ends up being consumed by the residents or flushed down the drain. Non-uniform corrosion (pinholes or pitting) is similar to a tire being punctured by a nail where the tire and the tire's function are destroyed in a short time period, at the spot where the puncture occurs. Just as is the case when a copper pipe pit occurs, only a small hole forms, but the pipe is no long useful or able to fulfill its function. With copper pipe, this small hole results in a pinhole leak in the pipe. This leak releases water and may cause extensive damage inside of homes as the pipes are typically installed inside of walls and can go undetected until collateral damage has occurred.

As an example of a similar situation that resulted in excessive copper pitting, Dr. Russell conducted a study in Orange County (Los Angeles, CA area) in 2016 (Russell 2016). It was observed that copper corrosion by pit formation caused the failure of copper piping systems in over 100,000 homes located in southern Orange County. This area is served by a very large diameter main that travels 50 miles to supply the water. During water transport the disinfectant levels were exhausted due to time spent in transport, which could take from one to five days depending upon water demand (velocity). In Orange County, there was no supplemental local boosting of the disinfectant at the terminus of the 50-mile pipeline, and the water purveyor had trouble providing a constant secondary disinfectant level during transport (MWD 2017).

In Orange County, CA, Dr. Russell found that the non-uniform corrosion was caused by pipe pitting initiators which were biofilms, supported by the lack of disinfectant. The biofilm causes a differential oxygen cell to form that was the pitting initiator. The pits will continue to advance due to corrosion for as long as the differential oxygen conditions continue. In Orange County, the houses with the pits required full house re-plumbing with PEX (plastic) piping to halt the through wall pit failures that resulted from the unstable disinfection residuals and biofilm formation.

These conditions were very similar to those in Flint, as discussed in the Section 10.1. During the Flint Water Crisis there was inadequate residual disinfection in the distribution system. The conditions under which pitting occurs include circumstances wherein there is inadequate disinfectant. As a result of the engineering process decisions, Flint was supplied with water that encouraged biological growth and resulted in the inability to maintain disinfectant residuals throughout the distribution system. Due to the low levels of disinfectants in the Flint distribution system, the treated Flint River water encouraged the conditions for biofilm production and, therefore, the conditions for encouraging MIC and the initiation of copper pipe pitting corrosion.

Regarding copper pitting corrosion, as was stated by Sarver and Edwards (2012):

Copper pitting is generally regarded as a two-step process in which pits are first formed (i.e., initiation) and then gradually penetrated through a metal surface (i.e., propagation). While initiation mechanisms are not well understood, and likely vary depending on physical and chemical exposure conditions, propagation proceeds via coupling of anodic reactions (i.e., copper oxidation) occurring at small anode sites (i.e., the pits) with cathodic reactions (i.e., oxygen or free chlorine reduction) occurring on relatively large surface areas. This differs from uniform copper corrosion, for which anodic and cathodic reactions effectively occur equally over the pipe surface. Pits can initiate at specific locations, including imperfections or breakdowns in the passive film layer that naturally occurs on copper surfaces in potable water or under particulate deposits that have settled onto the pipe surface. After initiation, pit propagation can be enhanced by differential concentration cells, due to dramatic chemical changes that occur in the very small volume of water localized inside the growing pit. Specifically, the pit water becomes very acidic due to Lewis acidity of released Cu^{+1} and ions, and ionic strength increases due to anion (e.g., Cl^- and SO_4^{2-}) transport to the pit to maintain electro-neutrality. In certain cases, the acidic and salty environment can promote sustained corrosion in the pit, and precipitation of copper salts (e.g., CuOH) forms a distinct mound of corrosion by-products (i.e., a tubercle).

The propagation of a copper pipe pit is supported by the corrosiveness of the treated Flint River water. Once a pit initiates, it is only a matter of time until through wall penetration occurs, and the pipe starts to leak. These leaks create significant collateral damage of mold growth and water damage from the leaks that occur inside of walls. Thus, corrosion pits in copper pipes are a form of ticking time bomb that will result in the need for full house plumbing replacement for those homes with copper plumbing. The only

feasible solution to address this problem is to replumb, which is exactly what was done in the case study discussed previously regarding Orange County, CA.

10.6 Other Sources of Lead

Lead sources within the home plumbing system include: leaded brass fittings (e.g., joints and valves), leaded brass fixtures (e.g., faucets), lead solder, the lead scale, and galvanized plating remaining on galvanized steel plumbing (e.g., pipes). The only strategy that will be successful in Flint requires the removal of these fixtures and the contaminated piping in total.

In addition to dissolved phase lead (lead that has solubilized in water), lead exists in homes in the form of particulate lead (minute separate particles of lead that are attached to rust and other mobile particles inside of the plumbing system). This particulate lead can settle into the joints, valves, nooks, cavities and crevasses of the corroded piping. These lead particulates are then episodically re-suspended into the drinking water supply where they can then be consumed by the drinking water user (i.e., the residents of Flint).

10.7 Summary

As has been shown above, there are six conditions under which structures were impacted by, and irreversibly damaged by, exposure to the corrosive Flint River Water.

1. Structures that tested with elevated lead levels in the drinking water.
2. Homes with lead laterals having interior plumbing or fixtures where lead dissolved and/or deposited, often with dissimilar metal connections.
3. Homes built before 1988 that were constructed with high lead solder. Homes built before 2014 with high lead brass valves and faucets.
4. All structures with plumbing materials that have deposited lead scales on the pipes, resulting from the reaction of the lead with the phosphate water additive.
5. All structures with dissimilar metals connections, e.g., steel pipe directly connected with brass faucets or copper pipe joined with high lead solder.
6. Structures with copper piping that were subject to enhanced corrosion rates due to MIC and pitting corrosion.

These six types of impacted structures all require similar repairs to rectify the problem. The only solution to reduce the resident's exposure to lead in their drinking water is to conduct full replacement of these valves, fixtures, and piping.

To reduce the lead exposure for the residents of Flint, these plumbing components must be replaced with fixtures and piping containing less than 0.25 percent lead that are in compliance with NSF 61/ NSF 372. Replacement removes corroded plumbing, and removes the ongoing source of lead via lead particulate and leaded scale release in the Flint drinking water.

LAN could have prevented the Flint Water Crisis by identifying the potential for the production of corrosive water from the Flint River, and implementing an optimal corrosion control treatment study. That study was required to be performed prior to the switch over to the Flint River water, and would have identified the need for corrosion control treatment. The failure of LAN to recommend an effective form of corrosion control resulted in enormous harm to human health and property.

Although Veolia was not retained until February 2015, it also could have prevented much of the harm by acting quickly to identify and address the corrosive water in the Flint system. The failure to immediately address those issues allowed for continued harm to human health and property. Many of the problems could have been mitigated by a recommendation for an immediate switch back to Detroit Water and Sewage Department (DWSD) water or at the minimum, the immediate implementation of corrosion control treatment.

11 Materials Reviewed

AB&H, 2002. *Treatability Study: Flint River*. LAN FLINT 00040694-00040785.

AECOM, Jones & Henry Engineers LTD, LAN, O'Malia Consulting, ROWE, Wade Trim Inc. *Preliminary Engineering Report: Lake Huron Water Supply: Karegnondi Water Authority.* September 2009.

Adeosun, O.O., 2014. *Water Distribution System Challenges and Solutions.* Water Online, September 9, 2014.

AWWA, 2005. *Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment.* American Water Works Association.

AWWA, 2017. *Internal Corrosion Control in Water Distribution Systems, 2nd Edition.* AWWA, 2017: M58.

Bae, Y., and D. Giammar., 2019. *Processes Controlling the Development of Effective Lead Corrosion Control with Orthophosphate.* WRF, 2019.

Cantor, A. F., et al., 2006. *Copper Pipe Failure by Microbially Influenced Corrosion.* Materials Performance, June 2006 p. 38-41.

Chen, 2019. *Deposition of Depin (Theping) Chen, Volumes I and II; Case No. 5:16-cv-10444.* November 25-26, 2019.

City of Flint, 2013. *Resolution Authorizing Change Order #2 to the Lockwood, Andrews & Newman Contract for the Implementation of Water Plant Operations.* November 18, 2013.

City of Flint, 2014. Annual Water Quality Report. City of Flint Michigan.

City of Flint, 2015. *Resolution to Veolia Water for Water Quality Consultant*. February 4, 2015.

City of Flint, 2018. *Annual Water Quality Report.* City of Flint Michigan.

Clark, B., S. Masters, and M. Edwards, 2014. *Profile Sampling to Characterize Particulate Lead Risks in Potable Water.* Environmental Science and Technology 2014, 48, 6836-6843.

Clark, B. N., S. V. Masters, and M. A. Edwards. *Lead Release to Drinking Water from Galvanized Steel Pipe Coatings.* Environmental Engineering Science, Aug 2015, 713-721.

Del Toral, M., 2015. *High Lead Levels in Flint, Michigan – Interim Report.* USEPA, Region 5, June 24, 2015.

DeSantis, M. K., et al., 2018. *Mineralogical Evidence of Galvanic Corrosion in Drinking Water Lead Pipe Joints.* Environmental Science and Technology, 2018 March, 52(6):3365-3374.

Detroit Water and Sewage Department, 2014. Water Quality Report. Published 2015.

Detroit Water and Sewage Department, 2015. Water Quality Report. Published 2016.

Gamble, R. B., 2020. *Expert Report of R. Bruce Gamble.* Ankura Consulting Group LLC, June, 2020

Gardoni, P., 2020. *Expert Report of Dr. Paolo Gardoni, Flint Plaintiffs Class Action Certification*. June, 26, 2020.

Great Lakes Water Authority (GLWA), 2016. *Corrosion Control and Water Testing: Response to Frequently Asked Questions about Lead and Copper in Water.* June 2016.

Edwards, M. and S. Triantafyllidou, 2007. *Chloride-to-Sulfate Mass Ratio and Lead Leaching in Water.* J. of the American Water Works Association, Volume 99, Issue 7, p. 96-109.

Edwards, M., 2015. *Research Update: Corrosivity of Flint Water to Iron Pipes in the City — A Costly Problem*. Flintwaterstudy.org, September 29, 2015.

Edwards, M., S. Roy, and W. Rhoads, 2015. *Lead testing results for water sampled by residents*. Flintwaterstudy.org, September 2015.

Fahey, W. J. 2019. *Deposition of William J. Fayhey, Volumes I & II; Case No. 5:16-cv-10444.* December 3-4, 2019.

FlintGIS, 2016. Maps and parcel data for 2016 provided by FlintGIS, City of Flint Department of Planning and Development.

Gadis, D. 2020. *Deposition of David Gadis, Volumes I & II; Case Nos. 5:16-cv-10444, 17-108644-NO, 16-106150-NM.* January 30-31, 2020.

Glasgow, 2020. *Deposition of Michael B. Glasgow, Volumes I, II, and III; Case No. 5:16-cv-10444.* February 24-26, 2020.

Gnagy, 2019. *Deposition of Marvin Gnagy, Volumes I and II; Case No. 5:16-cv-10444.* December 12-13, 2019.

Goovaerts, P. 2017a. *The Drinking Water Contamination Crisis in Flint: Modeling Temporal Trends of Lead Levels Since Returning to Detroit Water System.* Science of the Total Environment, 581-582:66.

Goovaerts, P., 2017b. *Monitoring the Aftermath of Flint Drinking Water Contamination Crisis: Another Case of Sampling Bias.* Science of the Total Environment, 590-591:139.

Goovaerts, P., 2017c. *How Geostatistics Can Help you Find Lead and Galvanized Water Service Lines: The Case of Flint, MI.* Science of the Total Environment, 599-600 (2017) 1552-1563.

Green, W. *Witness testimony of John Warren Green, D.C. File Nos. 16-TA-327-FY, 16TB-927-FY, 16-TB-1685-FY, 16TC-1685-FY.*

Green, W., 2020. *Deposition of Warren Green, Rough Draft Transcript.* June 25-26 & 28, 2020.

Hagerty, K., 2020. *Deposition of Kevin Hagerty; Case No.*

Larson, T. E. and R. V. Skold, 1958. *Laboratory Studies Relating Mineral Quality of Water to Corrosion of Steel and Cast Iron*. Corrosion, Vol. 14, No. 6, p. 285t-288t.

LAN and ROWE, 2011. *Analysis of the Flint River as a Permanent Water Supply for the City of Flint.* July 2011.

LAN 2013. *Proposal: Flint Water Treatment Plant Habilitation – Phase II.* June 10, 2013.

LAN and ROWE, 2013. *Proposed Scope of Upgrades to Flint WTP.* August 20, 2013.

LAN 2015a. *Operational Evaluation Report, City of Flint: Trihalomethane Formation Concern; FINAL.* February 27, 2015.

LAN, 2015b; *Operational Evaluation Report, City of Flint: Trihalomethane Formation Concern; FINAL: Response to May 2015 Sample Results.* August 27, 2015.

LAN 2016. *Response: Flint Water Advisory Task Force Questions to Lockwood, Andrews and Newnam.* March 1, 2016.

LAN 2020a. *Defendants LAN and LAD Answers to Class Plaintiffs' Interrogatories; Case No: 5:16-10444*.

LAN 2020b. *Defendants LAN and LAD Second Supplemental Amended Answers to Class Plaintiffs' Interrogatories; Case No: 5:16-10444*. April 13, 2020.

Larsen, K.R., 2016. *Corrosion caused lead-tainted water in Flint, Michigan*. Materials Performance, 55(6), 26-29.

Leonardi, J. M, and W. J. Gruhn, 2001. *Flint River Assessment*. State of Michigan, Department of Natural Resources, July 2001.

Liang, S., et al., 2013. *Controlling Chloramine Decay – A Bench-Scale Investigation*. Presentation at American Water Works Association Annual Conference, 2013.

Lytle, D.A., M.R. Shock, K. Wait, K. Cahalan, V. Bosscher, A. Porter, M. Del Toral, 2019. *Sequential Drinking Water Sampling as a Tool for Evaluating Lead in Flint, Michigan.* Water Research, 157 (2019)40-54.

Markowitz, G., and D. Rosner, 2000. *"Cater to Children": The Role of The Lead Industry in a Public Health Tragedy, 1900-1955.* American Journal of Public Health, January 2000, Vol. 90, No. 1.

Masten et al., 2016. *Flint Water Crisis: What Happened and Why?* Journal of the American Water Works Association, 108(12) 22-34.

Masten et al., 2019. *Lead and Copper Rule and Lead Levels in Flint's Water*. Journal of the American Water Works Association, September 2019, Vol 111, No. 9.

McFadden, M., R. Giani, P. Kwan, & S.H. Reiber, 2011. *Contributions to drinking water lead from galvanized iron corrosion scales*. Journal of the American Water Works Association, 103(4), 76.

Muylwyk et al., 2014. *Developing Corrosion Control for Drinking Water Systems*. AWWA Opflow. 2014; 40(11):24.

MWH, 2005. *Water Treatment: Principles and Design.* John Wiley and Sons.

Nakashima, J., 2020. *Deposition of Jeremy Nakashima, Civil Action No. 5:16-cv-10444-JEL-MKM.* June 22-23, 2020.

Nasuta, J., 2020. *Deposition of Joseph Nasuta, Case Nos. 5:16-10444, 17-108646-NO, 16-106150-NM.* December 5, 2020.

Nguyen, C. K., et al., 2010. *Impact of Chloride: Sulfate Mass Ratio (CSMR) Changes on Lead Leaching in Potable Water.* Water Research Foundation.

Nguyen C., et al, 2010a. *Slideshow: Impact of Chloride: Sulfate Mass Ratio (CSMR) Changes on Lead Leaching in Potable Water.* Presentation of research funded by USEPA and WRF, Project #4088.

Nguyen, C. K., K. R. Stone, M. A. Edwards, 2011. *Chloride-to-sulfate mass ratio: Practical studies in galvanic corrosion of lead solder.* Journal AWWA: 103:1. January 2011.

Nicholas, R. T., 2019. *Deposition of Robert T. Nicholas, Volumes I & II; Case Nos. 5:16-10444, 17-108646-NO, 16-106150-NM.* December 9 & 11, 2020.

Pavwoski, 2020. *Deposition of Mark Pavwoski; Case No. 5:16-cv-10444.* February 27, 2020.

Pieper, K. J, et al., 2018. *Evaluating Water Lead Levels During the Flint Water Crisis.* Environmental Science & Technology, 2018, 52, 8124-8132.

Pieper, K. J, M. Tang, and M. A. Edwards, 2017. Flint Water Crisis Caused by Interrupted Corrosion Control: Investigating "Ground Zero" Home. *Environmental Science and Technology.* 2017, 51, p. 2007-2014.

Pogorilich, D. A., 2020. *Expert Report of David A. Pogorilich*. Ankura Consulting, LLC, June [ ], 2020.

Roberge, P., 2006. *Corrosion Inspection and Monitoring*. Wiley-Interscience.

ROWE, December 2013; *City of Flint Water Reliability Study: Distribution System*

Roy, S., M. Tang, and M. A. Edwards, 2019. *Lead Release to Potable Water During the Flint Michgan Water Crisis as Revealed by Routine Biosolids Monitoring Data.* Water Research, 160 (2019) 475-483.
Russell, L. L., 2016. *Declration in Putlte Homes v. MWD.*

Sarver, E., and M. Edwards, 2012. *Inhigibition of Copper Pitting Corrosion in Aggressive Potable Water*. International Journal of Corrosion, Volume 2012, Article 857823.

Schneider, O.D. et al., 2011. *Comparison of Zinc Versus Non-Zinc Corrosion Control of Lead and Copper.* Water Research Foundation and EPA.

Schock, M. R. 2020. *Deposition of Michal R. Shock, Volumes I & II; Case No. 5:16-cv-104444 & 4:17-cv-11218*. May 5-6, 2020.

Scorsone, E. and N. Bateson, 2011. *Long-Term Crisis and Systematic Failure: Taking the Fiscal Stress of America's Older Cities Seriously; Case Study: City of Flint, Michigan.* Michigan State University, September 2011.

Sleeping Giant Environmental Consultants (SGEC), LLP, 2016. *Final Results of the Flint Surface Water Treatment Plant Evaluation*. Eastern Research Group and USEPA Office of Civil Enforcement, April 25-28, 2016. Schock Deposition Exhibit No. 26.

Snell Environmental Group (SEG), Inc. et al. 1998. *Preliminary Design, Plans and Proposed Equipment for Rehabilitation of the Flint Water Plant.* City of Flint, Michigan, April 10, 1998.

State of Michigan, 2016. *Flint Water Advisory Task Force: Final Report*. Office of the Governor Rick Snyder, State of Michigan, March 21st 2016.

Stone, K.S., 2010. *Chloride Sulfate Mass Ratio (CSMR) and Nitrate Acceleration of Galvanic Lead-Bearing Solder Corrosion*. Master's Thesis in Environmental Science & Engineering at Virginia Polytechnical Institute.

Triantafyllidou, S., J. Parks, and M. Edwards, 2007. *Lead Particles in Potable Water.* Journal of the American Water Works Association. June 2007 99:6 p. 107-117.

Triantafyllidou, S. and M. Edwards, 2012. *Lead in Tap Water and in Blood: Implications for Lead Exposure in the United States.* Critical Reviews in Environmental Science and Technology, 42:13, 1297-1352.

USEPA, 2002a. *Effects of Water Age on Distribution System Water Quality*. USEPA Office of Ground Water and Drinking Water, Office of Water (4601M), August 15, 2002.

USEPA, 2002b. *New or Repaired Water Mains*. USEPA Office of Ground Water and Drinking Water, Office of Water (4601M), August 15, 2002.

USEPA, 2008. *Lead and Copper Rule: A Quick Reference Guide*. United States Environmental Protection Agency, EPA 816-F-08-018, June 2008.

USEPA, 2014. *Effectiveness of the Preservation Protocol within EPA Method 200.8 for Soluble and Particulate Lead Recovery in Drinking Water.* USEPA, August, 2014; EPA/600/F-14/248.

USEPA, 2016. *Drinking Water Treatment and Distribution Water Quality During the Water Crisis in Flint.* Presentation at AWWA WQTC, Indianapolis, IN. November 2016.

USEPA, 2016a. *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems.* USEPA Office of Water (4606M), 816-B-16-003, March 2016.

USEPA & AWWARF, 2008. *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues.* AWWARF.

USGS, 1963. *Water Resources of Flint Area Michigan*. United States Geological Survey (USGS), 1499-E, 1963.

USGS, 2016. *Potential Corrosivity of Untreated Groundwater in the United States.* United States Geological Survey (USGS), 2016-5092.

Veolia, 2015a. *City of Flint, MI, City Council Public Works Committee: Interim Water Quality Report.* February 18, 2015. Veolia.

Veolia, 2015b. *Flint Michigan: Water Quality Report*. March 12, 2015. Veolia.

Veolia, 2015c. *Technical Memorandum: THM Treatment Strategies for Flint, Michigan.* March 30, 2015. Veolia. COF_FED_0016292-0016321.

Veolia 2015d. *Flint Spreadsheets: Natively Produced Documents.* February 27, 2015. VWNAOS059356-059368.

Veolia 2015e. *Response to Invitation to Bid Water Quality Consultant: Proposal No.: 15-573.* January 29, 2015. Veolia. VEOLIA 003116-003154. February 12, 2015. Veolia. VEOLIA 006599-006608.

Veolia 2015f. *Public Works Workshop: Preliminary Report.*

Wang, Y., G. Zhu and Z. Yang, 2019. *Analysis of Water Quality Characteristics for Water Distribution Systems*. Journal of Water Reuse and Desaliniation, 09.2, 2019, 152-162.

Williams, D.J., C.J. Parrett, W.R. Schock, C. Muhlen, P. Donnelly, D. Lytle, 2018. *Design and Testing of USEPA's Flint Pipe Rig for Corrosion Control Evaluation.* Journal AWWA, October 2018, 110:10.

Zahran, S., et al., 2018. *Assessment of Legionnaires' Disease Outbreak in Flint Michigan.* PNAS, February 5, 2018, E1730-E1739.

Zhu, N., and S. Roy, 2015. *The Unintended Consequences of Migrating to Flint River Water.* Flintwaterstudy.org. August 23, 2015.

12 Depositions and Court Appearances

Expert Fees for Dr. Larry L. Russell, P.E.

Consulting: $495/hr
Deposition: $750/hr
Court Appearances: $750/hr

Depositions and court appearances of Dr. Larry L. Russell, P.E.

Infinity HOA vs. 300 Spear Realty, Superior Court of San Francisco, May 2020
Armstrong HOA vs. Armstrong Development, San Francisco Superior Court, August 2019
Riverwatch vs. the City of Vacaville, Northern District Federal Court, November 2018
Bosen vs Kelly, Los Angeles Superior Court, August 2018
Bosen vs Kelly, Los Angeles Superior Court, July 2018
Cabins at Crooked Pines Owners Association vs South Minaret Development Company LLC Superior Court Mono County - January 2018
Candlestick Point - The Cove vs. Top Vision San Francisco Superior Court - November 2016
Bridgeview HOA vs. Bridgeview development San Francisco Superior Court April 2016

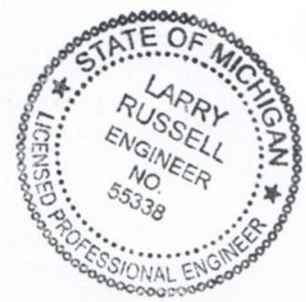
13 Signature and Stamp

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and recollection.

Executed this 30th day of June, 2020, in Tiburon, CA.

By:

Larry L. Russell, Ph.D.,P.E.



REED INTERNATIONAL LTD.

LARRY L. RUSSELL, Ph.D., P.E.

President

EDUCATION
Ph.D., Sanitary Engineering, University of California at Berkeley
M.S., Sanitary Engineering, University of California at Berkeley
B.S., Civil Engineering, University of California at Berkeley

REGISTRATION

Civil Engineer in California
Chemical Engineer in California
Corrosion Engineer in California
Professional Engineer in Arizona
Professional Engineer in Florida
Professional Engineer in Georgia
Professional Engineer in Hawaii
Professional Engineer in Idaho
Professional Engineer in Kansas
Professional Engineer in Kentucky
Professional Engineer in Michigan
Professional Engineer in Minnesota
Professional Engineer in New Mexico
Professional Engineer in New York
Professional Engineer in Nevada
Professional Engineer in North Carolina
Professional Engineer in Oregon
Professional Engineer in South Carolina
Professional Engineer in Texas
Professional Engineer in Washington

Dr. Larry L. Russell (continued)

Board Certified, American Academy of Environmental Engineers

A Engineering Contractor - 702818 B California, C-55 Water Conditioning, C-36 Plumbing, C-10 Electrical

Licensed Water Treatment operator in California, Hawaii, Nevada, and Texas

PATENTS

U.S. Patent No. 5,336,398 Water Treatment Device

U.S. Patent No. 5,975,628 Children=s High Chair Tray

U.S. Patent No. 5,992,684 Water Dispensing Device

U.S. Patent No. 6,103,097 Method and Apparatus for Lead Corrosion Control

U.S. Patent No. 6,423,208 Method and Apparatus for Lead Contamination Control

U.S. Patent No. 6,773,607 Ballast Water Treatment for Exotic Species Control

U.S. Patent No. 6,823,332 Information Storage and Retrieval Device

U.S. Patent No. 7,149,469 Method and System for Receiving Audio Broadcast via a Phone

U.S. Patent No. 7,194,459 Information Storage and Retrieval Device

U.S. Patent No. 7,186,327 Method and Apparatus for Scaling Control and In-Situ Cathodic Protection

Dr. Larry L. Russell (continued)

AREAS OF EXPERTISE

Applied environmental chemistry and engineering as related to concerns in air, water, soil with special emphasis on corrosion control and materials selection and performance, building materials performance, hazardous material management, hazardous materials regulations, explosions, combustion, storm water runoff, water source selection, and chemical usage in water and wastewater treatment.

Forensic evaluations on a wide variety of problems involving failure/corrosion of building materials ranging from copper, brass, lead and galvanized steel pipe and fittings, the corrosion of steel lathe in stucco applications, to the failure of PVC/PE/ABS piping materials, and the failure of EPDM gaskets and coated parts due to attack by chloramine. Dr. Russell has applied his knowledge of the chemistry of corrosion to the corrosion of lead service laterals in Paris FR and other locations around the U, structural mounts of the facade of the second tallest building in San Francisco, and to the issues of corrosion of common building construction materials and to evaluate both internal and external corrosion events. Recent evaluations have included issues, such as, the lead content of brass and its impact on drinking water quality, the dezincification of yellow brass in over 500,000 homes, the issue of pitting corrosion in over 100,000 homes in the southern Orange County area of California, and the issue of the growth of mold and dry rot as a result of the wetted conditions that occur due to pinhole leaks in copper pipe. Dr. Russell has gained significant experience with the behavior of metals and plastics used in the conveyance of both industrial and domestic water and wastewater. Recent projects have included the evaluation of erosion corrosion in copper piping systems in several large multi thousand unit developments and the behavior of PVC sewer pipes in San Francisco Bay mud.

Dr. Russell has recently been issued US and EU patents on the subject of drinking water lead corrosion control in lead service laterals, and he has more patents pending on the novel application of internal cathodic protection to piping systems. He has extensive expertise in the area of corrosion control and the determination of corrosion failure mechanisms in piping due to both internal and external conditions and also to the failure of structural systems due to corrosion.

Dr. Larry L. Russell (continued)

PREVIOUS EXPERIENCE

President - RUSSELL ENVIRONMENTAL ENGINEERING AND DEVELOPMENT (REED) CORPORATION - a small high tech environmental consulting firm specializing in sanitary engineering design and evaluation and forensic engineering evaluations.

Chairman - Aqua Resources, Inc. - Responsible for technical management of projects For industrial/hazardous waste management

Vice President - James M. Montgomery Consulting Engineers (MWH) - Manager of Industrial/Hazardous Waste Services for large consulting firm.

COMMITTEES

Chair of the Materials and Corrosion Committee of the IWA

U.S. Member (paid), by Invitation, of the European Union, COST 637 Committee on Corrosion

ORGANIZATIONS

AMERICAN WATER WORKS ASSOCIATION

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

INTERNATIONAL WATER ASSOCIATION (IWA)

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

INTERNATIONAL ASSOCIATION OF PLUMBING AND MECHANICAL OFFICIALS

P

Books and Thesis

Water Treatment - Principles and Design , 1985 .James M. Montgomery Consulting Engineers, Inc. co-author pp.696 Wiley Interscience

Chemical Aspects of Ground Water Recharge with Treated Wastewater Doctoral Thesis, November 1976, University of California at Berkeley

EPA Process Control Manual for Aerobic Biological Wastewater Treatment Facilities USEPA July 1977

Dr. Larry L. Russell (continued)

Water Recycling in the Food Processing Industry Office of Water Research Department of the Interior November 1980

Water Recycling in California's Food Processing Industry Office of Water Recycling State Water Resources Control Board July 1981

IWA Practice Guide on Lead Control in Water, IWA London 2011

IWA Practice Guide on Small Water Systems, IWA London 2011

IWA Practice Guide on Corrosion Control, IWA London 2012

Drinking Water Minerals and Mineral Balance, Springer First Edition 2015

Drinking Water Minerals and Mineral Balance, Springer Second Edition 2019

Courses Taught

Phase Separation for Hazardous Materials - University of California Extension - Davis, CA

Chemistry of Hazardous Materials - University of California Extension - Berkeley, CA

Technical Articles

Russell, L.L. and Thomas,J.F. "Increase of TDS by Ground Water Recharge". Water Pollution Control Federation 48th Annual Conference, Miami, October 1975

Russell, L.L., DeBoice J.N., and Carey,W.W. "Land Application of Winery Wastewater",Purdue Industrial Waste Conference, May 1976

Russell, L.L. and Thomas, J.F., "A Model For Estimating Ground Water Degradation" Hydraulics Division ASCE Specialty Conference on Modeling in Environmental Engineering, Purdue University, August 1976

Russell, L.L., DeCoite. D, Trussell, R.R., and Potter, L. "Operating the Activated Sludge Process" Water Pollution Control Federation 49th Annual Conference Minneapolis, October 1976

Dr. Larry L. Russell (continued)

Trussell,R.R., Russell, L.L., Thomas, J.F., " The Langelier Index" AWWA, Water Quality in the Distribution System, December 1977

Russell, L.L., Trussell, R.R, and DeBoice,J.N. "Removal of Iron and Manganese from Drinking Water" California AWWA Meeting, San Jose, CA October 1978

Russell, L.L., Creson, C.F. , and Connaroe, K." Water Recycling in the Food Processing Industry" Purdue Industrial Waste Conference May 1980

Russell, L.L., Ramaley, B." Treatment and Disposal of Hazardous Wastes from Tank Truck Washing Facilities" Purdue Industrial Waste Conference May, 1980

Russell, L.L. "Mixing Zones in Puerto Rico" presented at the request of the University of Puerto Rico, May 1982

Russell, L.L., Cain, C. "Impact of Priority Pollutants on Wastewater Treatment Plant Operations" Purdue Industrial Waste Conference May 1984

Russell, L.L.,"Economical Design of Hazardous Waste Studies" Water Pollution Control Federation Conference, 56th Annual Meeting, New Orleans, October 1984

Russell, L.L. "Alternatives for Small Quantity Discharges of Hazardous Waste" ASCE Specialty Conference, San Francisco, April 1985

Cain, C. Kerameda, V, Russell, L.L., "Indianapolis Pretreatment Program" Water Pollution Control Federation 57th Annual Meeting Kansas City, October 1985

Dr. Larry L. Russell (continued)

Russell, L. "The status of industrial discharge compliance with the U.S.E.P.A. NPDES program" by invitation to Generalitat de Catalunya Departament d'Industria i Energia, Barcolena, Spain December 10, 1987.

Russell, L. "Industrial Water Recycling/Waste Minimization" 5th Annual Industrial Waste Conference Anaheim, CA February 10, 1988

Russell, L. "Use of Ozone in Water Treatment" presentation by invitation for the Orange County Water District Symposium on Colored Water, Costa Mesa, CA April 1988

Russell, L. "Removal of Oil and Grease from Municipal Wastewater" by invitation to the California Water Pollution Control Federation - Industrial and Hazardous Waste Conference in San Jose, California on February 15, 1989.

Russell, L. , Medbery, S. "Development of the Local Pretreatment Limits for the City and County of San Francisco" For presentation at the Annual Water Pollution Control Federation meeting in San Francisco, CA October 1989.

Russell, L. "Recycled Wastewater Usage in the Food Processing Industry" by invitation to the Pennsylvania Food Processors Association, Hershey, PA November 1989

Russell, L. , Litwin, Y. "Conceptual Aspects of Remedial Investigations" Presentation at the NWWA Ground Water Action program Las Vegas, NV May 14, 1990.

Russell, L., Medbery, S.@Establishing Industrial Waste Standards for the City of San Francisco presented by invitation at the Pollution Control 97 conference in Bangkok, Thailand, November 12, 1997

Russell, L., Internal Cathodic Protection of Lead Pipes in Potable Water Systems. By invitation of the EU COST program in Antalya Turkey, October 24, 2007

Dr. Larry L. Russell (continued)

Russell, L., Copper Pipe Corrosion in Potable Water By invitation of the EU COST 637 program in Antalya Turkey, October 24, 2007

Russell, L., Lead Pipe Corrosion in Potable Water By invitation of the EU COST 637 program in Lisbon Portugal, October 30, 2008

Russell, L., Status of Partial Lead Pipe Replacement in the US by invitation of the EU COST 637 program in Budapest, Hungary, April 1, 2009